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(54) **SEMICONDUCTING POLYMERS**

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C07D 495/04; C09B 69/109; H01B 1/127;  
H01L 51/0036; H01L 51/0043; H01L  
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See application file for complete search history.

(56) **References Cited**

**U.S. PATENT DOCUMENTS**

7,572,879 B2 8/2009 Zahn et al.  
2004/0010115 A1 1/2004 Sotzing et al.

(Continued)

**FOREIGN PATENT DOCUMENTS**

EP 1 728 810 12/2006  
WO WO-2010 008672 1/2010

(Continued)

**OTHER PUBLICATIONS**

Liang, Y., Xiao, S., Feng, D., Yu, L.; "Control in Energy Levels of  
Conjugated Polymers for Photovoltaic Application", The Journal of  
Physical Chemistry C 2008, 112 (21), 7866-7871.\*

(Continued)

*Primary Examiner* — Peter F Godenschwager

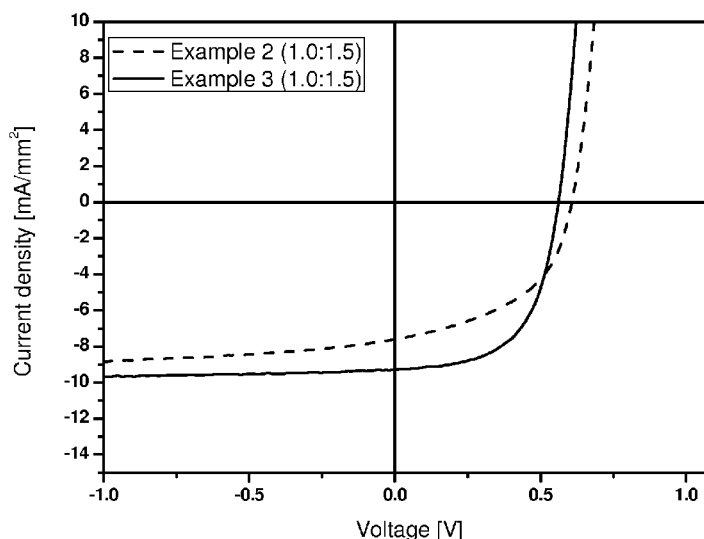
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(57) **ABSTRACT**

The invention relates to novel polymers containing repeating  
units based on thieno[3,4-b]thiophene, monomers and meth-  
ods for their preparation, their use as semiconductors in  
organic electronic (OE) devices, especially in organic photo-  
voltaic (OPV) devices, and to OE and OPV devices compris-  
ing these polymers.

**21 Claims, 1 Drawing Sheet**



- (51) **Int. Cl.** 2006/0223977 A1 10/2006 Zahn et al.  
**C08G 61/12** (2006.01) 2011/0124822 A1\* 5/2011 Yu et al. .... 525/389  
**H01B 1/12** (2006.01) 2012/0305853 A1 12/2012 Mitchell et al.  
**C09B 69/10** (2006.01)  
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## FOREIGN PATENT DOCUMENTS

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**2261/1426** (2013.01); **C08G 2261/1428**  
(2013.01); **C08G 2261/3223** (2013.01); **C08G**  
**2261/3243** (2013.01); **C08G 2261/414**  
(2013.01); **C08G 2261/51** (2013.01); **C08G**  
**2261/91** (2013.01); **H01L 51/0037** (2013.01);  
**H01L 51/4253** (2013.01); **H01L 2251/308**  
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WO WO2010008672 \* 1/2010  
WO WO-2011 098113 8/2011  
WO WO-2012 008672 1/2012

## OTHER PUBLICATIONS

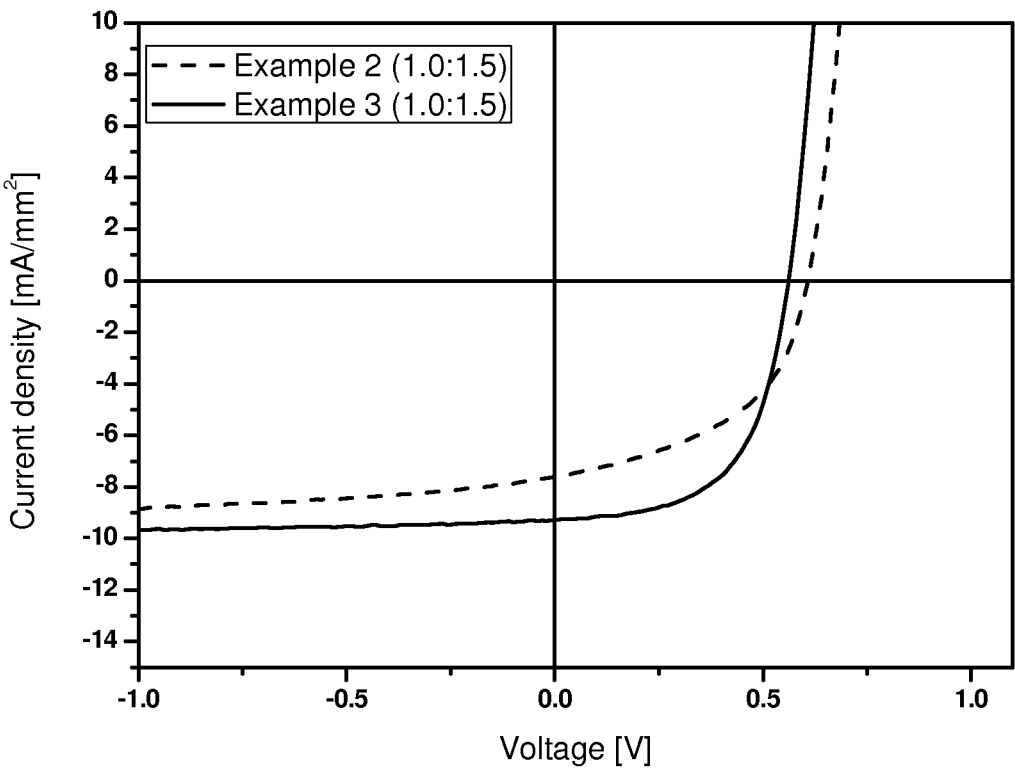
(56) **References Cited**

## U.S. PATENT DOCUMENTS

2005/0124784 A1 6/2005 Sotzing et al.

International Search Report for PCT/EP2011/002928, Date of the actual completion of the international search: Sep. 15, 2011, Date of mailing of the international search report: Feb. 20, 2012.  
Liang, Y. et al., "Control in Energy Levels of Conjugated Polymers for Photovoltaic Applications," J. Phys. Chem. C. 2008, vol. 112, pp. 7866-7871.  
Korea Advanced Inst Sci & Tech, "Method and device for designing a current supply and collection device for a transportation system using an electric vehicle," Espacenet, Publication Date: Jan. 19, 2012; English Abstract of WO-2012 008672.

\* cited by examiner



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## SEMICONDUCTING POLYMERS

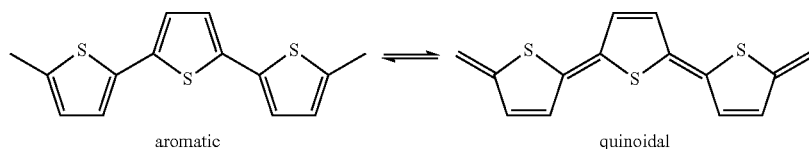
## FIELD OF THE INVENTION

The invention relates to novel polymers containing repeating units based on thieno[3,4-b]thiophene, monomers and methods for their preparation, their use as semiconductors in organic electronic (OE) devices, especially in organic photovoltaic (OPV) devices, and to OE and OPV devices comprising these polymers.

## BACKGROUND OF THE INVENTION

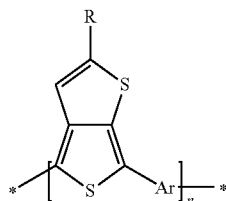
In recent years there has been growing interest in the use of semiconducting polymers for electronic applications. One particular area of importance is organic photovoltaics (OPV). Polymers have found use in OPVs as they allow devices to be manufactured by solution-processing techniques such as spin casting, dip coating or ink jet printing. Solution processing can be carried out cheaper and on a larger scale compared to the evaporative techniques used to make inorganic thin film devices. Currently, polymer based photovoltaic devices are achieving efficiencies up to 7%.

A class of polymers that is currently achieving the highest efficiencies in polymer based photovoltaic devices is based on units that have a high quinoidal contribution. Poly (thiophene), for example, can exist in both the aromatic and quinoidal state as shown below:



A quinoidal structure reduces the torsion between adjacent rings, which results in a more planar polymer backbone leading to an extension of the effective conjugation length. It is generally observed in conjugated polymers that an increase in the conjugation length results in a decrease of the bandgap, leading to a higher degree of absorbed incident light.

The quinoidal state can be stabilised by fusing an aromatic ring to the thiophene backbone. The fused ring is itself only fully aromatic when the backbone is in the quinoidal state. This means there is a strong desire for the polymer to be in the quinoidal state. Previous work has demonstrated the use of a thieno[3,4-b]thiophene (1) [see Y. Liang; Y. Wu; D. Feng; S.-T. Tsai; H.-J. Son; G. Li; L. Yu, *J. Am. Chem. Soc.*, 2009, 131 (1), 56-57], as shown below (wherein R is an alkyl group and Ar is an aryl group), to reduce the bandgap.



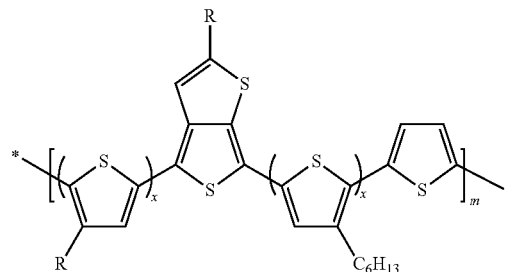
However, the synthesis of polymer (1) involves an unstable monomer, namely a 4,6-dibromothiopheno[3,4-b]thiophene,

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which complicates the polymer synthesis by leading to unpredictable polymer molecular weights that lead to varying polymer performance.

WO 2010/008672 A1 discloses semiconducting conjugated polymers of formula (2) and their use in OPV devices.

(2)



wherein R is polyfluoroalkyl, polychloroalkyl or an ester, R' is alkyl, alkoxy, aryl, aryloxy, heteroaryl or heteroaryloxy, x is an integer from 1 to 12, and m is an integer from 1 to 200.

However, these polymers have limited opportunities for fine-tuning of the HOMO and LUMO energy level positions. Furthermore, the positioning of the alkyl side chains limits the utilisation of phenylene ring based comonomers, as such

configurations would result in significant steric hindrance due to outward positioning of alkyl substituents on the thiophene rings.

There is still a need for organic semiconducting (OSC) materials that are easy to synthesize, especially by methods suitable for mass production, show good structural organization and film-forming properties, exhibit good electronic properties, especially a high charge carrier mobility, good processability, especially a high solubility in organic solvents, and high stability in air. Especially for use in OPV cells, there is a need for OSC materials having a low bandgap, which enable improved light harvesting by the photoactive layer and can lead to higher cell efficiencies.

It was an aim of the present invention to provide compounds for use as organic semiconducting materials that do not have the drawbacks of prior art materials as described above, are easy to synthesize, especially by methods suitable for mass production, and do especially show good processability, high stability, good solubility in organic solvents, high charge carrier mobility, and a low bandgap. Another aim of the invention was to extend the pool of OSC materials available to the expert. Other aims of the present invention are immediately evident to the expert from the following detailed description.

The inventors of the present invention have found that these aims can be achieved by providing conjugated semiconducting polymers as claimed in this application.

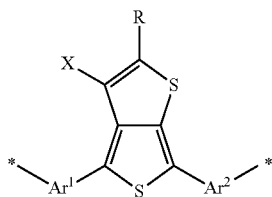
The monomers and polymers of the present invention are especially suitable for large scale production. At the same

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time, they show good processability, high solubility in organic solvents, low bandgap, high charge carrier mobility and high oxidative stability, and are promising materials for organic electronic OE devices, especially for OPV devices.

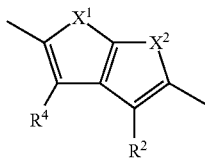
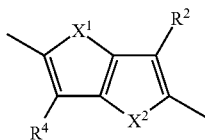
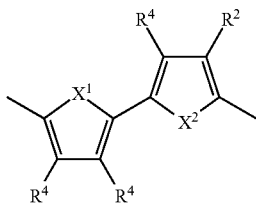
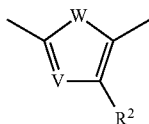
## SUMMARY OF THE INVENTION

The invention relates to a conjugated polymer comprising one or more identical or different repeating units of formula I:

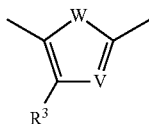


wherein the asterisks indicate a link to neighbored groups,

Ar¹ is on each occurrence identically or differently a group selected from the following formulae

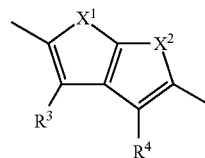
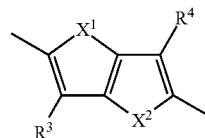
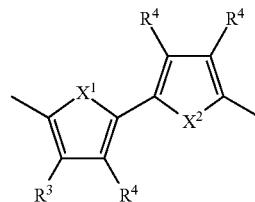


Ar² is on each occurrence identically or differently a group selected from the following formulae



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-continued



W is S, Se or O,

V is CH or N,

X¹ and X² are, on each occurrence identically or differently, and independently of each other, O, S or Se,

X is H or F,

R on each occurrence identically or differently, denotes F, Cl, Br, I, CN, or straight-chain, branched or cyclic alkyl with 1 to 35 C atoms, in which one or more non-adjacent C atoms are optionally replaced by —O—, —S—, —CO—, —CO—O—, —O—CO—, —O—CO—O—, —CR⁰=CR⁰⁰— or —C≡C— and in which one or more H atoms are optionally replaced by F, Cl, Br, I or CN, or denotes aryl, heteroaryl, aryloxy, heteroaryloxy, arylcarbonyl, heteroarylcarbonyl, arylcarbonyloxy, heteroarylcarbonyloxy, aryloxy carbonyl or heteroaryloxy carbonyl having 4 to 30 ring atoms that is unsubstituted or substituted by one or more non-aromatic groups R¹,

R⁰ and R⁰⁰ are independently of each other H or optionally substituted carbyl or hydrocarbyl optionally comprising one or more hetero atoms,

R¹ is on each occurrence identically or differently H, halogen, —CN, —NC, —NCO, —NCS, —OCN, —SCN, —C(=O)NR⁰R⁰⁰, —C(=O)X⁰, —C(=O)R⁰, —NH₂, —NR⁰R⁰⁰, —SH, —SR⁰, —SO₃H, —SO₂R⁰, —OH, —NO₂, —CF₃, —SF₅, optionally substituted silyl, carbyl or hydrocarbyl with 1 to 40 C atoms that is optionally substituted and optionally comprises one or more hetero atoms, or P-Sp-,

R² and R³ on each occurrence identically or differently, and independently of each other, have one of the meanings given for R or R¹, which is preferably different from H,

R⁴ has on each occurrence identically or differently one of the meanings given for R or R¹,

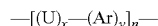
P is a polymerisable or crosslinkable group,

Sp is a spacer group or a single bond,

X⁰ is halogen.

The invention further relates to a conjugated polymer comprising identical or different repeating units, wherein at least one repeating unit contains a unit of formula I, and optionally comprising one or more units Ar selected from aryl and heteroaryl units that are optionally substituted.

Preferably these polymers are selected of formula III:



IIe

IIg

IIh

IIa

IIb

IIc

IId

IIe

IIg

IIh

IIi

IIj

IIk

IIl

IIm

IIn

III

wherein

U is, on each occurrence identically or differently, a unit of formula I as described above and below,

Ar is, on each occurrence identically or differently, an aryl or heteroaryl group that is optionally substituted,

x is on each occurrence identically or differently 0, 1 or 2, wherein in at least one repeating unit, i.e. in at least one unit  $-(U)_x-(Ar)_y-$ , x is 1,

y is on each occurrence identically or differently 0, 1 or 2, n is an integer >1.

The invention further relates to monomers containing a unit of formula I, which are suitable for the preparation of polymers as described above and below.

The invention further relates to a mixture or blend comprising one or more polymers according to the present invention and one or more additional compounds or polymers which are preferably selected from compounds and polymers having semiconducting, charge transport, hole/electron transport, hole/electron blocking, electrically conducting, photoconducting or light emitting properties.

The invention further relates to a formulation comprising one or more polymers, mixtures or blends according to the present invention and optionally one or more solvents, preferably selected from organic solvents.

The invention further relates to the use of polymers, mixtures, blends and formulations according to the present invention as charge transport, semiconducting, electrically conducting, photoconducting or light emitting material in optical, electrooptical, electronic, electroluminescent or photoluminescent components or devices.

The invention further relates to a charge transport, semiconducting, electrically conducting, photoconducting or light emitting material or component comprising one or more polymers, polymer blends of formulations according to the present invention.

The invention further relates to an optical, electrooptical or electronic component or device comprising one or more polymers, polymer blends, formulations, components or materials according to the present invention.

The optical, electrooptical, electronic electroluminescent and photoluminescent components or devices include, without limitation, organic field effect transistors (OFET), thin film transistors (TFT), integrated circuits (IC), logic circuits, capacitors, radio frequency identification (RFID) tags, devices or components, organic light emitting diodes (OLED), organic light emitting transistors (OLET), flat panel displays, backlights of displays, organic photovoltaic devices (OPV), solar cells, laser diodes, photoconductors, photodetectors, electrophotographic devices, electrophotographic recording devices, organic memory devices, sensor devices, charge injection layers, charge transport layers or interlayers in polymer light emitting diodes (PLEDs), organic plasmon-emitting diodes (OPEDs), Schottky diodes, planarising layers, antistatic films, polymer electrolyte membranes (PEM), conducting substrates, conducting patterns, electrode materials in batteries, alignment layers, biosensors, biochips, security markings, security devices, and components or devices for detecting and discriminating DNA sequences.

#### DETAILED DESCRIPTION OF THE INVENTION

The monomers and polymers of the present invention are easy to synthesize and exhibit several advantageous properties, like a low bandgap, a high charge carrier mobility, a high solubility in organic solvents, a good processability for the device manufacture process, a high oxidative stability and a long lifetime in electronic devices.

In addition, they show the following advantageous properties:

i) The 4,6-bis(5-bromo-thiophen-2-yl)-thieno[3,4-b]thiophene monomers exhibit better thermal, light and air stability compare to the 4,6-dibromo-thieno[3,4-b]thiophene monomer counterpart.

ii) The two additional thiophene rings on both sides of the thieno[3,4-b]thiophene group extend the conjugation length, thereby lowering the band gap of the resultant polymer and improving the light harvesting ability of the material.

iii) Additional solubility can be introduced into the polymer by inclusion of solubilising groups at the R, R<sup>2</sup> or R<sup>3</sup> positions.

iv) Additional fine-tuning of the electronic energies (HOMO/LUMO levels) by either careful selection of thiophene R<sup>2</sup> and R<sup>3</sup> group on each side of 4,6-di-thiophen-2-yl-thieno[3,4-b]thiophene or co-polymerisation with appropriate co-monomer(s) should afford candidate materials for organic photovoltaic applications.

v) The increase in monomer stability results in better reproducibility of the polymer molecular weights obtained, and therefore in better reproducibility of the polymer performance, compared to polymers as described in prior art, like e.g. in WO 2010/008672 A.

The term “polymer” generally means a molecule of high relative molecular mass, the structure of which essentially comprises the multiple repetition of units derived, actually or conceptually, from molecules of low relative molecular mass (PAC, 1996, 68, 2291). The term “oligomer” generally means a molecule of intermediate relative molecular mass, the structure of which essentially comprises a small plurality of units derived, actually or conceptually, from molecules of lower relative molecular mass (PAC, 1996, 68, 2291). In a preferred sense according to the present invention a polymer means a compound having >1, preferably ≥5 repeating units, and an oligomer means a compound with >1 and <10, preferably <5, repeating units.

Above and below, in a formula showing a polymer or a repeating unit, like formula I and its subformulae, an asterisk (“\*”) denotes a linkage to an adjacent repeating unit or a terminal group in the polymer chain.

The terms “repeating unit” and “monomeric unit” mean the constitutional repeating unit (CRU), which is the smallest constitutional unit the repetition of which constitutes a regular macromolecule, a regular oligomer molecule, a regular block or a regular chain (PAC, 1996, 68, 2291).

The term “leaving group” means an atom or group (charged or uncharged) that becomes detached from an atom in what is considered to be the residual or main part of the molecule taking part in a specified reaction (see also PAC, 1994, 66, 1134).

The term “conjugated” means a compound containing mainly C atoms with sp<sup>2</sup>-hybridisation (or optionally also sp-hybridisation), which may also be replaced by hetero atoms. In the simplest case this is for example a compound with alternating C—C single and double (or triple) bonds, but does also include compounds with units like 1,3-phenylene. “Mainly” means in this connection that a compound with naturally (spontaneously) occurring defects, which may lead to interruption of the conjugation, is still regarded as a conjugated compound.

Unless stated otherwise, the molecular weight is given as the number average molecular weight M<sub>n</sub>, or weight average molecular weight M<sub>w</sub>, which is determined by gel permeation chromatography (GPC) against polystyrene standards in eluent solvents such as tetrahydrofuran, trichloromethane (TCM, chloroform), chlorobenzene or 1,2,4-trichloroben-

zene. Unless stated otherwise, trichloromethane is used as solvent. The degree of polymerization (n) means the number average degree of polymerization given as  $n = M_n/M_L$ , wherein  $M_L$  is the molecular weight of the single repeating unit as described in J. M. G. Cowie, *Polymers: Chemistry & Physics of Modern Materials*, Blackie, Glasgow, 1991.

The term "carbyl group" as used above and below denotes any monovalent or multivalent organic radical moiety which comprises at least one carbon atom either without any non-carbon atoms (like for example  $-\text{C}\equiv\text{C}-$ ), or optionally combined with at least one non-carbon atom such as N, O, S, P, Si, Se, As, Te or Ge (for example carbonyl etc.). The term "hydrocarbyl group" denotes a carbyl group that does additionally contain one or more H atoms and optionally contains one or more hetero atoms like for example N, O, S, P, Si, Se, As, Te or Ge.

A carbyl or hydrocarbyl group comprising a chain of 3 or more C atoms may also be straight-chain, branched and/or cyclic, including spiro and/or fused rings.

Preferred carbyl and hydrocarbyl groups include alkyl, alkoxy, alkylcarbonyl, alkoxy carbonyl, alkylcarbonyloxy and alkoxy carbonyloxy, each of which is optionally substituted and has 1 to 40, preferably 1 to 25, very preferably 1 to 18 C atoms, furthermore optionally substituted aryl or aryloxy having 6 to 40, preferably 6 to 25 C atoms, furthermore alkylaryloxy, arylcarbonyl, aryloxy carbonyl, arylcarbonyloxy and aryloxy carbonyloxy, each of which is optionally substituted and has 6 to 40, preferably 7 to 40 C atoms, wherein all these groups do optionally contain one or more hetero atoms, preferably selected from N, O, S, P, Si, Se, As, Te and Ge.

The carbyl or hydrocarbyl group may be a saturated or unsaturated acyclic group, or a saturated or unsaturated cyclic group. Unsaturated acyclic or cyclic groups are preferred, especially aryl, alkenyl and alkynyl groups (especially ethynyl). Where the  $\text{C}_1$ - $\text{C}_{40}$  carbyl or hydrocarbyl group is acyclic, the group may be straight-chain or branched. The  $\text{C}_1$ - $\text{C}_{40}$  carbyl or hydrocarbyl group includes for example: a  $\text{C}_1$ - $\text{C}_{40}$  alkyl group, a  $\text{C}_1$ - $\text{C}_{40}$  alkoxy or oxaalkyl group, a  $\text{C}_2$ - $\text{C}_{40}$  alkenyl group, a  $\text{C}_2$ - $\text{C}_{40}$  alkynyl group, a  $\text{C}_3$ - $\text{C}_{40}$  allyl group, a  $\text{C}_4$ - $\text{C}_{40}$  alkyldienyl group, a  $\text{C}_4$ - $\text{C}_{40}$  polyenyl group, a  $\text{C}_6$ - $\text{C}_{18}$  aryl group, a  $\text{C}_6$ - $\text{C}_{40}$  alkylaryl group, a  $\text{C}_6$ - $\text{C}_{40}$  arylalkyl group, a  $\text{C}_4$ - $\text{C}_{40}$  cycloalkyl group, a  $\text{C}_4$ - $\text{C}_{40}$  cycloalkenyl group, and the like. Preferred among the foregoing groups are a  $\text{C}_1$ - $\text{C}_{20}$  alkyl group, a  $\text{C}_2$ - $\text{C}_{20}$  alkenyl group, a  $\text{C}_2$ - $\text{C}_{20}$  alkynyl group, a  $\text{C}_3$ - $\text{C}_{20}$  allyl group, a  $\text{C}_4$ - $\text{C}_{20}$  alkyldienyl group, a  $\text{C}_6$ - $\text{C}_{12}$  aryl group and a  $\text{C}_4$ - $\text{C}_{20}$  polyenyl group, respectively. Also included are combinations of groups having carbon atoms and groups having hetero atoms, like e.g. an alkynyl group, preferably ethynyl, that is substituted with a silyl group, preferably a trialkylsilyl group.

Aryl and heteroaryl preferably denote a mono-, bi- or tricyclic aromatic or heteroaromatic group with 4 to 30 ring atoms that may also comprise condensed rings and is optionally substituted with one or more groups L as defined above.

Very preferred substituents L are selected from halogen, most preferably F, or alkyl, alkoxy, oxaalkyl, thioalkyl, fluoroalkyl and fluoroalkoxy with 1 to 12 C atoms or alkenyl, alkynyl with 2 to 12 C atoms.

Especially preferred aryl and heteroaryl groups are phenyl in which, in addition, one or more CH groups may be replaced by N, naphthalene, thiophene, selenophene, thienothiophene, dithienothiophene, fluorene and oxazole, all of which can be unsubstituted, mono- or polysubstituted with L as defined above. Very preferred rings are selected from pyrrole, preferably N-pyrrole, pyridine, preferably 2- or 3-pyridine, pyrimidine, thiophene preferably 2-thiophene, selenophene, prefer-

ably 2-selenophene, thieno[3,2-b]thiophene, thiazole, thiadiazole, oxazole and oxadiazole, especially preferably thiophene-2-yl, 5-substituted thiophene-2-yl or pyridine-3-yl, all of which can be unsubstituted, mono- or polysubstituted with L as defined above.

An alkyl or alkoxy radical, i.e. where the terminal  $\text{CH}_2$  group is replaced by  $-\text{O}-$ , can be straight-chain or branched. It is preferably straight-chain, has 2, 3, 4, 5, 6, 7 or 8 carbon atoms and accordingly is preferably ethyl, propyl, butyl, pentyl, hexyl, heptyl, octyl, ethoxy, propoxy, butoxy, pentoxy, hexoxy, heptoxy, or octoxy, furthermore methyl, nonyl, decyl, undecyl, dodecyl, tridecyl, tetradecyl, pentadecyl, nonoxy, decoxy, undecoxy, dodecoxy, tridecoxy or tetradecoxy, for example.

An alkenyl group, wherein one or more  $\text{CH}_2$  groups are replaced by  $-\text{CH}=\text{CH}-$  can be straight-chain or branched. It is preferably straight-chain, has 2 to 10 C atoms and accordingly is preferably vinyl, prop-1-, or prop-2-enyl, but-1-, 2- or but-3-enyl, pent-1-, 2-, 3- or pent-4-enyl, hex-1-, 2-, 3-, 4- or hex-5-enyl, hept-1-, 2-, 3-, 4-, 5- or hept-6-enyl, oct-1-, 2-, 3-, 4-, 5-, 6- or oct-7-enyl, non-1-, 2-, 3-, 4-, 5-, 6-, 7- or non-8-enyl, dec-1-, 2-, 3-, 4-, 5-, 6-, 7-, 8- or dec-9-enyl.

Especially preferred alkenyl groups are  $\text{C}_2$ - $\text{C}_7$ -1E-alkenyl,  $\text{C}_4$ - $\text{C}_7$ -3E-alkenyl,  $\text{C}_5$ - $\text{C}_7$ -4-alkenyl,  $\text{C}_6$ - $\text{C}_7$ -5-alkenyl and  $\text{C}_7$ -6-alkenyl, in particular  $\text{C}_2$ - $\text{C}_7$ -1E-alkenyl,  $\text{C}_4$ - $\text{C}_7$ -3E-alkenyl and  $\text{C}_5$ - $\text{C}_7$ -4-alkenyl. Examples for particularly preferred alkenyl groups are vinyl, 1E-propenyl, 1E-butenyl, 1E-pentenyl, 1E-hexenyl, 1E-heptenyl, 3-butenyl, 3E-pentenyl, 3E-hexenyl, 3E-heptenyl, 4-pentenyl, 4Z-hexenyl, 4E-hexenyl, 4Z-heptenyl, 5-hexenyl, 6-heptenyl and the like. Groups having up to 5 C atoms are generally preferred.

An oxaalkyl group, i.e. where one  $\text{CH}_2$  group is replaced by  $-\text{O}-$ , is preferably straight-chain 2-oxapropyl (=methoxymethyl), 2-(=ethoxymethyl) or 3-oxabutyl (=2-methoxyethyl), 2-, 3-, or 4-oxapentyl, 2-, 3-, 4-, or 5-oxahexyl, 2-, 3-, 4-, 5-, or 6-oxaheptyl, 2-, 3-, 4-, 5-, 6- or 7-oxaoctyl, 2-, 3-, 4-, 5-, 6-, 7- or 8-oxanonyl or 2-, 3-, 4-, 5-, 6-, 7-, 8- or 9-oxadecyl, for example. Oxaalkyl, i.e. where one  $\text{CH}_2$  group is replaced by  $-\text{O}-$ , is preferably straight-chain 2-oxapropyl (=methoxymethyl), 2-(=ethoxymethyl) or 3-oxabutyl (=2-methoxyethyl), 2-, 3-, or 4-oxapentyl, 2-, 3-, 4-, or 5-oxahexyl, 2-, 3-, 4-, 5-, or 6-oxaheptyl, 2-, 3-, 4-, 5-, 6- or 7-oxaoctyl, 2-, 3-, 4-, 5-, 6-, 7- or 8-oxanonyl or 2-, 3-, 4-, 5-, 6-, 7-, 8- or 9-oxadecyl, for example.

In an alkyl group wherein one  $\text{CH}_2$  group is replaced by  $-\text{O}-$  and one by  $-\text{CO}-$ , these radicals are preferably neighbored. Accordingly these radicals together form a carbonyloxy group  $-\text{CO}-\text{O}-$  or an oxycarbonyl group  $-\text{O}-\text{CO}-$ . Preferably this group is straight-chain and has 2 to 6 C atoms. It is accordingly preferably acetyloxy, propionyloxy, butyryloxy, pentanoyloxy, hexanoyloxy, acetyloxymethyl, propionyloxymethyl, butyryloxymethyl, pentanoyloxymethyl, 2-acetyloxyethyl, 2-propionyloxy-ethyl, 2-butyryloxyethyl, 3-acetyloxypropyl, 3-propionyloxypropyl, 4-acetyloxybutyl, methoxycarbonyl, ethoxycarbonyl, propoxycarbonyl, butoxycarbonyl, pentoxycarbonyl, methoxycarbonylmethyl, ethoxy-carbonylmethyl, propoxycarbonylmethyl, butoxycarbonylmethyl, 2-(methoxycarbonyl)ethyl, 2-(ethoxycarbonyl)ethyl, 2-(propoxycarbonyl)ethyl, 3-(methoxycarbonyl)propyl, 3-(ethoxycarbonyl)propyl, 4-(methoxycarbonyl)-butyl.

An alkyl group wherein two or more  $\text{CH}_2$  groups are replaced by  $-\text{O}-$  and/or  $-\text{COO}-$  can be straight-chain or branched. It is preferably straight-chain and has 3 to 12 C atoms. Accordingly it is preferably bis-carboxy-methyl, 2,2-bis-carboxy-ethyl, 3,3-bis-carboxy-propyl, 4,4-bis-carboxy-butyl, 5,5-bis-carboxy-pentyl, 6,6-bis-carboxy-hexyl, 7,7-

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bis-carboxy-heptyl, 8,8-bis-carboxy-octyl, 9,9-bis-carboxy-nonyl, 10,10-bis-carboxy-decyl, bis-(methoxycarbonyl)-methyl, 2,2-bis-(methoxycarbonyl)-ethyl, 3,3-bis-(methoxycarbonyl)-propyl, 4,4-bis-(methoxycarbonyl)-butyl, 5,5-bis-(methoxycarbonyl)-pentyl, 6,6-bis-(methoxycarbonyl)-hexyl, 7,7-bis-(methoxycarbonyl)-heptyl, 8,8-bis-(methoxycarbonyl)-octyl, bis-(ethoxycarbonyl)-methyl, 2,2-bis-(ethoxycarbonyl)-ethyl, 3,3-bis-(ethoxycarbonyl)-propyl, 4,4-bis-(ethoxycarbonyl)-butyl, 5,5-bis-(ethoxycarbonyl)-hexyl.

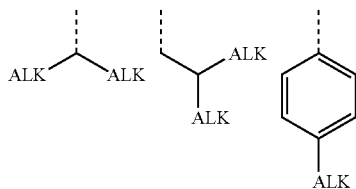
A thioalkyl group, i.e. where one  $\text{CH}_2$  group is replaced by  $-\text{S}-$ , is preferably straight-chain thiomethyl ( $-\text{SCH}_3$ ), 1-thioethyl ( $-\text{SCH}_2\text{CH}_3$ ), 1-thiopropyl ( $-\text{SCH}_2\text{CH}_2\text{CH}_3$ ), 1-(thiobutyl), 1-(thiopentyl), 1-(thiohexyl), 1-(thioheptyl), 1-(thiooctyl), 1-(thiononyl), 1-(thiododecyl), 1-(thioundecyl) or 1-(thiododecyl), wherein preferably the  $\text{CH}_2$  group adjacent to the  $\text{sp}^2$  hybridised vinyl carbon atom is replaced.

A fluoroalkyl group is preferably straight-chain perfluoroalkyl  $\text{C}_i\text{F}_{2i+1}$ , wherein  $i$  is an integer from 1 to 15, in particular  $\text{CF}_3$ ,  $\text{C}_2\text{F}_5$ ,  $\text{C}_3\text{F}_7$ ,  $\text{C}_4\text{F}_9$ ,  $\text{C}_5\text{F}_{11}$ ,  $\text{C}_6\text{F}_{13}$ ,  $\text{C}_7\text{F}_{15}$  or  $\text{C}_8\text{F}_{17}$ , very preferably  $\text{C}_6\text{F}_{13}$ .

The above-mentioned alkyl, alkoxy, alkenyl, oxaalkyl, thioalkyl, carbonyl and carbonyloxy groups can be achiral or chiral groups. Particularly preferred chiral groups are 2-butyl (=1-methylpropyl), 2-methylbutyl, 2-methylpentyl, 3-methylpentyl, 2-ethylhexyl, 2-propylpentyl, in particular 2-methylbutyl, 2-methylbutoxy, 2-methylpentoxy, 3-methylpentoxy, 2-ethylhexoxy, 1-methylhexoxy, 2-octyloxy, 2-oxa-3-methylbutyl, 3-oxa-4-methylpentyl, 4-methylhexyl, 2-hexyl, 2-octyl, 2-nonyl, 2-decyl, 2-dodecyl, 6-methoxyoctoxy, 6-methyloctoxy, 6-methyloctanoyloxy, 5-methylheptyloxy-carbonyl, 2-methylbutyryloxy, 3-methylvaleroyloxy, 4-methylhexanoyloxy, 2-chloropropionyloxy, 2-chloro-3-methylbutyryloxy, 2-chloro-4-methyl-valeryl-oxy, 2-chloro-3-methylvaleryloxy, 2-methyl-3-oxapentyl, 2-methyl-3-oxahexyl, 1-methoxypropyl-2-oxy, 1-ethoxypropyl-2-oxy, 1-propoxypropyl-2-oxy, 1-butoxypropyl-2-oxy, 2-fluorooctyloxy, 2-fluorodecyloxy, 1,1,1-trifluoro-2-octyloxy, 1,1,1-trifluoro-2-octyl, 2-fluoromethyloctyloxy for example. Very preferred are 2-hexyl, 2-octyl, 2-octyloxy, 1,1,1-trifluoro-2-hexyl, 1,1,1-trifluoro-2-octyl and 1,1,1-trifluoro-2-octyloxy.

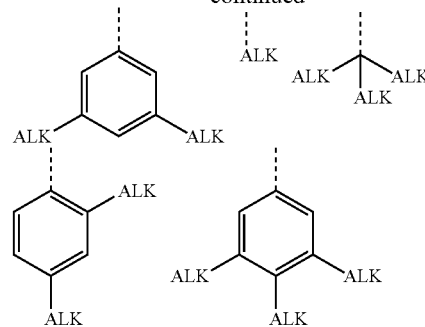
Preferred achiral branched groups are isopropyl, isobutyl (=methylpropyl), isopentyl (=3-methylbutyl), tert. butyl, isopropoxy, 2-methyl-propoxy and 3-methylbutoxy.

In another preferred embodiment of the present invention,  $\text{R}$ ,  $\text{R}^2$  or  $\text{R}^3$  are selected from primary, secondary or tertiary alkyl or alkoxy with 1 to 30 C atoms, wherein one or more H atoms are optionally replaced by F, or aryl, aryloxy, heteroaryl or heteroaryloxy that is optionally alkylated or alkoxyated and has 4 to 30 ring atoms. Very preferred groups of this type are selected from the group consisting of the following formulae



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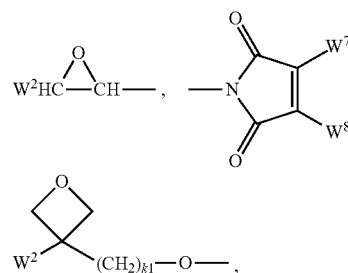
wherein "ALK" denotes optionally fluorinated, preferably linear, alkyl or alkoxy with 1 to 20, preferably 1 to 12 C-atoms, in case of tertiary groups very preferably 1 to 9 C atoms, and the dashed line denotes a link to the ring to which these groups are attached. Especially preferred among these groups are those wherein all ALK subgroups are identical.

$-\text{CY}^1=\text{CY}^2-$  is preferably  $-\text{CH}=\text{CH}-$ ,  $-\text{CF}=\text{CF}-$  or  $-\text{CH}=\text{C}(\text{CN})-$ .

Halogen is F, Cl, Br or I, preferably F, Cl or Br.

The polymers may also be substituted with a polymerisable or crosslinkable reactive group, which is optionally protected during the process of forming the polymer. Particular preferred polymers of this type are those of formula I wherein  $\text{R}^1$  denotes P-Sp. These polymers are particularly useful as semiconductors or charge transport materials, as they can be crosslinked via the groups P, for example by polymerisation in situ, during or after processing the polymer into a thin film for a semiconductor component, to yield crosslinked polymer films with high charge carrier mobility and high thermal, mechanical and chemical stability.

Preferably the polymerisable or crosslinkable group P is selected from  $\text{CH}_2=\text{CW}^1-\text{CO}-\text{O}-$ ,  $\text{CH}_2=\text{CW}^1-\text{CO}-$ ,



$\text{CH}_2=\text{CW}^2-(\text{O})_{k1}-$ ,  $\text{CW}^1=\text{CH}-\text{CO}-(\text{O})_{k3}-$ ,  
 $\text{CW}^1=\text{CH}-\text{CO}-\text{NH}-$ ,  $\text{CH}_2=\text{CW}^1-\text{CO}-\text{NH}-$ ,  
 $\text{CH}_3-\text{CH}=\text{CH}-\text{O}-$ ,  $(\text{CH}_2=\text{CH})_2\text{CH}-\text{OCO}-$ ,  
 $(\text{CH}_2=\text{CH}-\text{CH}_2)_2\text{CH}-\text{O}-\text{CO}-$ ,  $(\text{CH}_2=\text{CH})_2\text{CH}-$   
 $\text{O}-$ ,  $(\text{CH}_2=\text{CH}-\text{CH}_2)_2\text{N}-$ ,  $(\text{CH}_2=\text{CH}-\text{CH}_2)_2\text{N}-$   
 $\text{CO}-$ ,  $\text{HO}-\text{CW}^2\text{W}^3-$ ,  $\text{HS}-\text{CW}^2\text{W}^3-$ ,  $\text{HW}^2\text{N}-$ ,  
 $\text{HO}-\text{CW}^2\text{W}^3-\text{NH}-$ ,  $\text{CH}_2=\text{CH}-(\text{CO}-\text{O})_{k1}-$   
 $\text{Phe}-(\text{O})_{k2}-$ ,  $\text{CH}_2=\text{CH}-(\text{CO})_{k1}-\text{Phe}-(\text{O})_{k2}-$ ,  $\text{Phe}-$   
 $\text{CH}=\text{CH}-$ ,  $\text{HOOC}-$ ,  $\text{OCN}-$ , and  $\text{W}^4\text{W}^5\text{W}^6\text{Si}-$ , with  $\text{W}^1$   
 being H, F, Cl, CN,  $\text{CF}_3$ , phenyl or alkyl with 1 to 5 C-atoms,  
 in particular H,  $\text{C}_1$  or  $\text{CH}_3$ ,  $\text{W}^2$  and  $\text{W}^3$  being independently of  
 each other H or alkyl with 1 to 5 C-atoms, in particular H,  
 methyl, ethyl or n-propyl,  $\text{W}^4$ ,  $\text{W}^5$  and  $\text{W}^6$  being indepen-  
 dently of each other Cl, oxaalkyl or oxacarbonylalkyl with 1  
 to 5 C-atoms,  $\text{W}^7$  and  $\text{W}^8$  being independently of each other

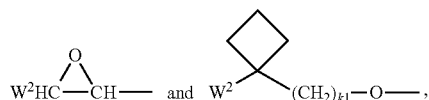


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H, Cl or alkyl with 1 to 5 C-atoms, Phe being 1,4-phenylene that is optionally substituted by one or more groups L as defined above,  $k_1$ ,  $k_2$  and  $k_3$  being independently of each other 0 or 1,  $k_3$  preferably being 1, and  $k_4$  being an integer from 1 to 10.

Alternatively P is a protected derivative of these groups which is non-reactive under the conditions described for the process according to the present invention. Suitable protective groups are known to the ordinary expert and described in the literature, for example in Green, "Protective Groups in Organic Synthesis", John Wiley and Sons, New York (1981), like for example acetals or ketals.

Especially preferred groups P are  $\text{CH}_2=\text{CH}-\text{CO}-\text{O}-$ ,  $\text{CH}_2=\text{C}(\text{CH}_3)-\text{CO}-\text{O}-$ ,  $\text{CH}_2=\text{CF}-\text{CO}-\text{O}-$ ,  $\text{CH}_2=\text{CH}-\text{O}-$ ,  $(\text{CH}_2=\text{CH})_n\text{CH}-\text{O}-\text{CO}-$ ,  $(\text{CH}_2=\text{CH})_2\text{CH}-\text{O}-$ ,



or protected derivatives thereof. Further preferred groups P are selected from the group consisting of vinyloxy, acrylate, methacrylate, fluoroacrylate, chloracrylate, oxetan and epoxy groups, very preferably from an acrylate or methacrylate group.

Polymerisation of group P can be carried out according to methods that are known to the ordinary expert and described in the literature, for example in D. J. Broer; G. Challa; G. N. Mol, *Macromol. Chem.*, 1991, 192, 59.

The term "spacer group" is known in prior art and suitable spacer groups Sp are known to the ordinary expert (see e.g. Pure Appl. Chem. 73(5), 888 (2001)). The spacer group Sp is preferably of formula  $\text{Sp}'\text{-X}'$ , such that  $\text{P-Sp}'$  is  $\text{P-Sp}'\text{-X}'$ , wherein

$\text{Sp}'$  is alkylene with up to 30 C atoms which is unsubstituted or mono- or polysubstituted by F, Cl, Br, I or CN, it being also possible for one or more non-adjacent  $\text{CH}_2$  groups to be replaced, in each case independently from one another, by  $-\text{O}-$ ,  $-\text{S}-$ ,  $-\text{NH}-$ ,  $-\text{NR}^0$ ,  $-\text{SiR}^0\text{R}^{00}$ ,  $-\text{CO}-$ ,  $-\text{COO}-$ ,  $-\text{OCO}-$ ,  $-\text{OCO}-$ ,  $-\text{S}-\text{CO}-$ ,  $-\text{CO}-\text{S}-$ ,  $-\text{CH}=\text{CH}-$  or  $-\text{C}\equiv\text{C}-$  in such a manner that O and/or S atoms are not linked directly to one another,

$\text{X}'$  is  $-\text{O}-$ ,  $-\text{S}-$ ,  $-\text{CO}-$ ,  $-\text{COO}-$ ,  $-\text{COO}-$ ,  $-\text{O}-\text{COO}-$ ,  $-\text{CO}-\text{NR}^0$ ,  $-\text{NR}^0-\text{CO}-$ ,  $-\text{NR}^0-\text{CO}-\text{NR}^{00}$ ,  $-\text{OCH}_2-$ ,  $-\text{CH}_2\text{O}-$ ,  $-\text{SCH}_2-$ ,  $-\text{CH}_2\text{S}-$ ,  $-\text{CF}_2\text{O}-$ ,  $-\text{OCF}_2-$ ,  $-\text{CF}_2\text{S}-$ ,  $-\text{SCF}_2-$ ,  $-\text{CF}_2\text{CH}_2-$ ,  $-\text{CH}_2\text{CF}_2-$ ,  $-\text{CF}_2\text{CF}_2-$ ,  $-\text{CH}=\text{N}-$ ,  $-\text{N}=\text{CH}-$ ,  $-\text{N}=\text{N}-$ ,  $-\text{CH}=\text{CR}^0$ ,  $-\text{CY}^1=\text{CY}^2$ ,  $-\text{C}\equiv\text{C}-$ ,  $-\text{CH}=\text{CH}-\text{COO}-$ ,  $-\text{OCO}-\text{CH}=\text{CH}-$  or a single bond,

$\text{R}^0$  and  $\text{R}^{00}$  are independently of each other H or alkyl with 1 to 12 C-atoms, and

$\text{Y}^1$  and  $\text{Y}^2$  are independently of each other H, F, Cl or CN.

$\text{X}'$  is preferably  $-\text{O}-$ ,  $-\text{S}-$ ,  $-\text{OCH}_2-$ ,  $-\text{CH}_2\text{O}-$ ,  $-\text{SCH}_2-$ ,  $-\text{CH}_2\text{S}-$ ,  $-\text{CF}_2\text{O}-$ ,  $-\text{OCF}_2-$ ,  $-\text{CF}_2\text{S}-$ ,  $-\text{SCF}_2-$ ,  $-\text{CH}_2\text{CH}_2-$ ,  $-\text{CF}_2\text{CH}_2-$ ,  $-\text{CH}_2\text{CF}_2-$ ,  $-\text{CF}_2\text{CF}_2-$ ,  $-\text{CH}=\text{N}-$ ,  $-\text{N}=\text{CH}-$ ,  $-\text{N}=\text{N}-$ ,  $-\text{CH}=\text{CR}^0$ ,  $-\text{CY}^1=\text{CY}^2$ ,  $-\text{C}\equiv\text{C}-$  or a single bond, in particular  $-\text{O}-$ ,  $-\text{S}-$ ,  $-\text{C}\equiv\text{C}-$ ,

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$-\text{CY}^1=\text{CY}^2-$  or a single bond. In another preferred embodiment  $\text{X}'$  is a group that is able to form a conjugated system, such as  $-\text{C}\equiv\text{C}-$  or  $-\text{CY}^1=\text{CY}^2-$ , or a single bond.

Typical groups  $\text{Sp}'$  are, for example,  $-(\text{CH}_2)_p-$ ,  $-(\text{CH}_2\text{CH}_2\text{O})_q-\text{CH}_2\text{CH}_2-$ ,  $-\text{CH}_2\text{CH}_2-\text{S}-\text{CH}_2\text{CH}_2-$  or  $-\text{CH}_2\text{CH}_2-\text{NH}-\text{CH}_2\text{CH}_2-$  or  $-(\text{SiR}^0\text{R}^{00}-\text{O})_p-$ , with p being an integer from 2 to 12, q being an integer from 1 to 3 and  $\text{R}^0$  and  $\text{R}^{00}$  having the meanings given above.

Preferred groups  $\text{Sp}'$  are ethylene, propylene, butylene, pentylene, hexylene, heptylene, octylene, nonylene, decylene, undecylene, dodecylene, octadecylene, ethyleneoxyethylene, methyleneoxybutylene, ethylene-thioethylene, ethylene-N-methyl-iminoethylene, 1-methylalkylene, ethenylene, propenylene and butenylene for example.

The polymers containing units of formula I, especially those of formula III, are preferably selected of formula IIIa



wherein U, Ar, n, x and y have the meanings of formula III, and

$\text{R}^5$  and  $\text{R}^6$  have independently of each other one of the meanings of  $\text{R}^1$ , preferably halogen, or denote H,  $-\text{CH}_2\text{Cl}$ ,  $-\text{CHO}$ ,  $-\text{CH}=\text{CH}_2$ ,  $-\text{SiR}^0\text{R}^0\text{R}^0$ ,  $-\text{SnR}^0\text{R}^0\text{R}^0$ ,  $-\text{BR}^0\text{R}^0$ ,  $-\text{B}(\text{OR}')(\text{OR}'')$ ,  $-\text{B}(\text{OH})_2$ , or P-Sp, wherein P and Sp are as defined in formula I, and  $\text{R}'$ ,  $\text{R}''$  and  $\text{R}'''$  have independently of each other one of the meanings of  $\text{R}^0$  given in formula I, and two of  $\text{R}'$ ,  $\text{R}''$  and  $\text{R}'''$  may also form a ring together with the hetero atom to which they are attached.

In the polymers according to the present invention, the total number of repeating units n is preferably 5, very preferably 10, most preferably 50, and preferably up to 500, very preferably up to 1,000, most preferably up to 2,000, including any combination of the aforementioned lower and upper limits of n.

The polymers of the present invention include homopolymers and copolymers, like statistical or random copolymers, alternating copolymers and block copolymers, as well as combinations thereof.

Block copolymers may for example comprise or consist of one or more blocks formed by units of formula I and one or more blocks formed by units Ar, wherein Ar has one of the meanings as described above and below.

Another aspect of the invention relates to monomers of formula Ia



wherein U is a unit of formula I or selected from its preferred subformulae or preferred meanings as described above and below, and  $\text{R}^5$  and  $\text{R}^6$  have the meanings given in formula IIIa.

Especially preferred are monomers of formula Ia wherein  $\text{R}^5$  and  $\text{R}^6$  are, preferably independently of each other, selected from the group consisting of Cl, Br, I, O-tosylate, O-triflate, O-mesylate, O-nonaflate,  $-\text{SiMe}_2\text{F}$ ,  $-\text{SiMeF}_2$ ,  $-\text{O}-\text{SO}_2\text{Z}^1$ ,  $-\text{B}(\text{OZ}^2)_2$ ,  $-\text{CZ}^3=\text{C}(\text{Z}^3)_2$ ,  $-\text{C}\equiv\text{CH}$  and  $-\text{Sn}(\text{Z}^4)_3$ , wherein  $\text{Z}^{1-4}$  are selected from the group consisting of alkyl and aryl, each being optionally substituted, and two groups  $\text{Z}^2$  may also form a cyclic group.

Preferably the repeating units of formula I, and the monomers of formula Ia and polymers of formula III and IIIa containing them, are selected from the following list of preferred embodiments, including any combination thereof:

in all repeating units x is 1 and y is 0, thereby forming a homopolymer of units U of the formula  $-\text{U}-$ ,

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in all repeating units x is 1 and y is 1, thereby forming an alternating copolymer of units U and Ar of the formula  $-\text{[U-Ar]}_n-$ ,

Ar<sup>1</sup> is of formula IIa and Ar<sup>2</sup> is of formula IIe,

Ar<sup>1</sup> is of formula IIb and Ar<sup>2</sup> is of formula IIf,

Ar<sup>1</sup> is of formula IIc and Ar<sup>2</sup> is of formula IIg,

Ar<sup>1</sup> is of formula IId and Ar<sup>2</sup> is of formula IIh,

in formula IIb, IIc and IId, X<sup>1</sup> and X<sup>2</sup> are S,

in formula IIg and IIh, X<sup>1</sup> and X<sup>2</sup> are S,

in formula IIb, IIc and IId, X<sup>1</sup> and X<sup>2</sup> are Se,

in formula IIg and IIh, X<sup>1</sup> and X<sup>2</sup> are Se,

in formula IIb, IIc and IId, one of X<sup>1</sup> and X<sup>2</sup> is S and the other is Se,

in formula IIg and IIh, one of X<sup>1</sup> and X<sup>2</sup> is S, and the other is Se,

in formula IIa and IIe W is S,

in formula IIa and IIe W is Se,

in formula IIa and IIe W is O,

in formula IIa and IIe V is N,

in formula IIa and IIe V is CH,

X is H,

X is F,

Ar is selected from 1,4-phenylene, thiophene-2,5-diyl,

selenophene-2,5-diyl, thieno[3,2-b]thiophene-2,5-diyl,

thieno[2,3-b]thiophene-2,5-diyl, selenopheno[3,2-b]se-

lenophene-2,5-diyl, selenopheno[2,3-b]selenophene-2,

5-diyl, selenopheno[3,2-b]thiophene-2,5-diyl, sele-

nopheno[2,3-b]thiophene-2,5-diyl, benzo[1,2-b:4,5-b']

dithiophene-2,6-diyl, 2,2-dithiophene, 2,2-

diselenophene, dithieno[3,2-b:2',3'-d]silole-5,5-diyl,

4H-cyclopenta[2,1-b:3,4-b']dithiophene-2,6-diyl, car-

bazole-2,7-diyl, fluorene-2,7-diyl, indaceno[1,2-b:5,6-

b']dithiophene-2,7-diyl, benzo[1",2":4,5;4",5":4',5']bis

(silolo[3,2-b:3',2'-b]thiophene)-2,7-diyl, phenanthro[1,

10,9,8-c,d,e,f,g]carbazole-2,7-diyl, benzo[2,1,3]

thiadiazole-4,7-diyl, benzo[2,1,3]selenadiazole-4,7-

diyl, benzo[2,1,3]oxadiazole-4,7-diyl,

2H-benzotriazole-4,7-diyl, 3,4-difluorothiophene-2,5-

diyl, thieno[3,4-b]pyrazine-2,5-diyl, quinoxaline-5,8-

diyl, thieno[3,4-b]thiophene-4,6-diyl, thieno[3,4-b]

thiophene-6,4-diyl, 3,6-di-thien-2-yl-pyrrolo[3,4-c]

pyrrole-1,4-dione, or [1,3]thiazolo[5,4-d][1,3]thiazole-

2,5-diyl,

all of which are unsubstituted, or mono- or polysubstituted, preferably with R, R<sup>1</sup> or R<sup>2</sup> as defined above and below,

n is at least 5, preferably at least 10, very preferably at least 50, and up to 2,000, preferably up to 500.

Mw is at least 5,000, preferably at least 8,000, very preferably at least 10,000, and preferably up to 300,000, very preferably up to 100,000,

in formula IIb, IIc and IId, one or more groups R<sup>4</sup> are different from H,

in formula IIg, IIh and IIh, one or more groups R<sup>4</sup> are different from H,

R is primary alkyl, alkoxy or thioalkyl with 1 to 30 C atoms, secondary alkyl, alkoxy or thioalkyl with 3 to 30 C atoms, or tertiary alkyl, alkoxy or thioalkyl with 4 to 30 C atoms, wherein in all these groups one or more H atoms are optionally replaced by F,

R is aryl, heteroaryl, aryloxy or heteroaryloxy, each of which is optionally alkylated or alkoxyated and has 4 to 30 ring atoms,

R is  $-\text{CO}-\text{R}^y$ ,  $-\text{CO}-\text{O}-\text{R}^y$ , or  $-\text{O}-\text{CO}-\text{R}^y$ , very preferably  $-\text{CO}-\text{R}^y$  or  $-\text{CO}-\text{O}-\text{R}^y$ , wherein R<sup>y</sup> is

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straight-chain, branched or cyclic alkyl with 1 to 30 C atoms, in which one or more non-adjacent C atoms are optionally replaced by  $-\text{O}-$ ,  $-\text{S}-$ ,  $-\text{CO}-$ ,  $-\text{CO}-\text{O}-$ ,  $-\text{O}-\text{CO}-$ ,  $-\text{O}-\text{CO}-\text{O}-$ ,  $-\text{CR}^0=\text{CR}^{00}-$  or  $-\text{C}\equiv\text{C}-$  and in which one or more H atoms are optionally replaced by F, Cl, Br, I or CN, or R<sup>y</sup> is aryl, aryloxy, heteroaryl or heteroaryloxy having 4 to 30 ring atoms that is unsubstituted or substituted by one or more non-aromatic groups R<sup>1</sup> as defined in formula I,

R<sup>y</sup> is primary alkyl with 1 to 30 C atoms, very preferably with 1 to 15 C atoms, secondary alkyl with 3 to 30 C atoms, or tertiary alkyl with 4 to 30 C atoms, wherein in all these groups one or more H atoms are optionally replaced by F,

R<sup>y</sup> is  $-(\text{CH}_2)_o-\text{CR}^a\text{R}^b\text{R}^c$ , wherein o is 0, 1, 2, 3, 4 or 5, very preferably 0, 1 or 2, and R<sup>a</sup>, R<sup>b</sup> and R<sup>c</sup> are independently of each other C<sub>1</sub>-C<sub>12</sub>-alkyl, very preferably C<sub>1</sub>-C<sub>8</sub>-alkyl, which is optionally substituted by one or more F atoms, and wherein optionally one of R<sup>a</sup>, R<sup>b</sup> and R<sup>c</sup> is H,

R<sup>y</sup> is aryl, heteroaryl, aryloxy or heteroaryloxy, each of which is optionally alkylated or alkoxyated and has 4 to 30 ring atoms,

R<sup>x</sup> is alkyl with 1 to 15 C atoms,

R<sup>0</sup> and R<sup>00</sup> are selected from H or C<sub>1</sub>-C<sub>10</sub>-alkyl,

R<sup>1</sup> is alkyl, alkoxy, alkylcarbonyl, alkylcarbonyloxy or alkoxy carbonyl with 1 to 30 C atoms, wherein one or more H atoms are optionally replaced by F,

R<sup>2</sup> and R<sup>3</sup> have the same meaning,

R<sup>2</sup> and R<sup>3</sup> are different from H,

R<sup>4</sup> is H,

R<sup>2</sup>, R<sup>3</sup> and R<sup>4</sup>, when being different from H, are selected from straight-chain alkyl, alkoxy and thioalkyl with 1 to 20 C atoms, wherein one or more H atoms are optionally replaced by F,

R<sup>2</sup>, R<sup>3</sup> and R<sup>4</sup>, when being different from H, are selected from branched alkyl, alkoxy and thioalkyl with 3 to 20 C atoms, wherein one or more H atoms are optionally replaced by F, which is preferably secondary alkyl, alkoxy or thioalkyl with 3 to 20 C atoms, or tertiary alkyl, alkoxy or thioalkyl with 4 to 20 C atoms, wherein in all the aforementioned groups one or more H atoms are optionally replaced by F,

R<sup>2</sup>, R<sup>3</sup> and R<sup>4</sup>, when being different from H, are selected from aryl, heteroaryl, aryloxy and heteroaryloxy, each of which is optionally alkylated or alkoxyated and has 4 to 30 ring atoms,

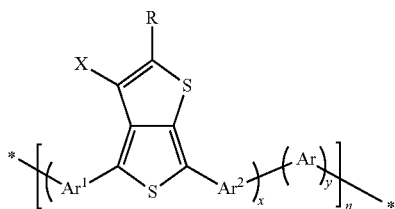
R<sup>5</sup> and R<sup>6</sup> are selected from H, halogen,  $-\text{CH}_2\text{Cl}$ ,  $-\text{CHO}$ ,  $-\text{CH}=\text{CH}_2$ ,  $-\text{SiR}^i\text{R}^j\text{R}^k$ ,  $-\text{SnR}^i\text{R}^j\text{R}^k$ ,  $-\text{BR}^i\text{R}^j$ ,  $-\text{B}(\text{OR}^i)(\text{OR}^j)$ ,  $-\text{B}(\text{OH})_2$ , P-Sp, C<sub>1</sub>-C<sub>20</sub>-alkyl, C<sub>1</sub>-C<sub>20</sub>-alkoxy, C<sub>2</sub>-C<sub>20</sub>-alkenyl, C<sub>1</sub>-C<sub>20</sub>-fluoroalkyl and optionally substituted aryl or heteroaryl, wherein R<sup>i</sup>, R<sup>j</sup> and R<sup>k</sup> are as defined in formula IIa,

R<sup>5</sup> and R<sup>6</sup> are, preferably independently of each other, selected from the group consisting of Cl, Br, I, O-tosylate, O-triflate, O-mesylate, O-nonaflate,  $-\text{SiMe}_2\text{F}$ ,  $-\text{SiMeF}_2$ ,  $-\text{O}-\text{SO}_2\text{Z}^1$ ,  $-\text{B}(\text{OZ}^2)_2$ ,  $-\text{CZ}^3=\text{C}(\text{Z}^4)_2$ ,  $-\text{C}\equiv\text{CH}$  and  $-\text{Sn}(\text{Z}^4)_3$ , wherein Z<sup>1-4</sup> are selected from the group consisting of alkyl and aryl, each being optionally substituted, and two groups Z<sup>2</sup> may also form a cyclic group, very preferably from Br,

one or more of R, R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup> and R<sup>y</sup> denotes or contains a group P-Sp-

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Preferred polymers of formula III are selected of formula IIII



wherein R, X, R<sup>2</sup>, R<sup>3</sup>, Ar<sup>1</sup>, Ar<sup>2</sup>, Ar, x, y and n have the meanings given in formula I and III or one of the preferred meanings given above and below.

Further preferred polymers of formula III are selected of formula IIIIa



IIIa

wherein "chain" is a polymer chain of formula IIII, and R<sup>5</sup> and R<sup>6</sup> have the meanings given in formula IIa or one of the preferred meanings given above and below.

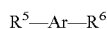
The polymers of the present invention can be synthesized according to or in analogy to methods that are known to the skilled person and are described in the literature. Other methods of preparation can be taken from the examples. For example, they can be suitably prepared by aryl-aryl coupling reactions, such as Yamamoto coupling, Suzuki coupling, Stille coupling, Sonogashira coupling, Heck coupling or Buchwald coupling. Suzuki coupling and Yamamoto coupling are especially preferred.

The monomers which are polymerised to form the repeat units of the polymers can be prepared according to methods which are known to the person skilled in the art.

Preferably the polymers are prepared from monomers of formula Ia or its preferred embodiments as described above and below.

Another aspect of the invention is a process for preparing a polymer by coupling one or more identical or different monomeric units of formula I or monomers of formula Ia with each other and/or with one or more comonomers in a polymerisation reaction, preferably in an aryl-aryl coupling reaction.

Suitable and preferred comonomers are those of the formula



wherein Ar, R<sup>5</sup> and R<sup>6</sup> are as defined above.

Preferred methods for polymerisation are those leading to C—C-coupling or C—N-coupling, like Suzuki polymerisation, as described for example in WO 00/53656, Yamamoto polymerisation, as described in for example in T. Yamamoto et al., Progress in Polymer Science 1993, 17, 1153-1205 or in WO 2004/022626 A1, and Stille coupling. For example, when synthesizing a linear polymer by Yamamoto polymerisation, monomers as described above having two reactive halide groups is preferably used. When synthesizing a linear polymer by Suzuki polymerisation, preferably a monomer as described above is used wherein at least one reactive group is a boronic acid or boronic acid derivative group.

Suzuki polymerisation may be used to prepare homopolymers as well as statistical, alternating and block random copolymers. Statistical or block copolymers can be prepared

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for example from the above monomers of formula Ia wherein one of the reactive groups is halogen and the other reactive group is a boronic acid or boronic acid derivative group. The synthesis of statistical, alternating and block copolymers is described in detail for example in WO 03/048225 A2 or WO 2005/014688 A2.

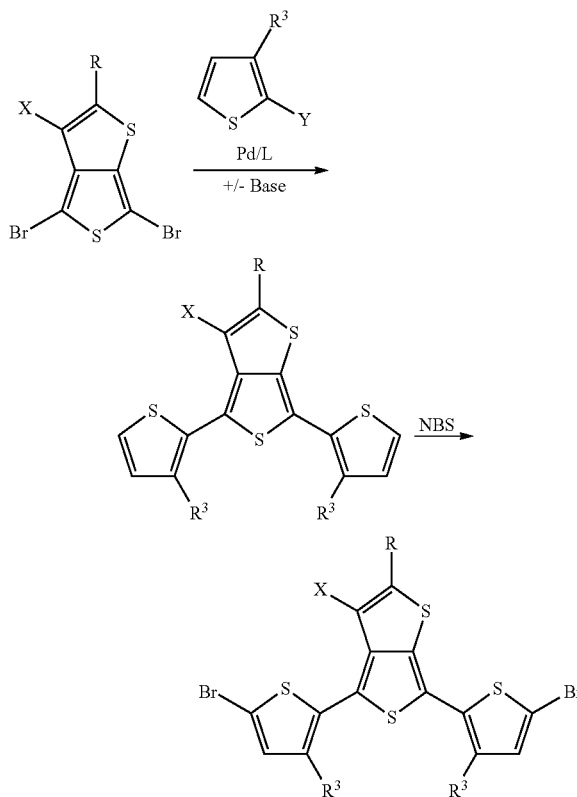
Suzuki polymerisation employs a Pd(0) complex or a Pd(II) salt. Preferred Pd(0) complexes are those bearing at least one phosphine ligand such as Pd(Ph<sub>3</sub>P)<sub>4</sub>. Another preferred phosphine ligand is tris(ortho-tolyl)phosphine, i.e. Pd(o-Tol)<sub>4</sub>. Preferred Pd(II) salts include palladium acetate, i.e. Pd(OAc)<sub>2</sub>. Suzuki polymerisation is performed in the presence of a base, for example sodium carbonate, potassium phosphate or an organic base such as tetraethylammonium carbonate. Yamamoto polymerisation employs a Ni(0) complex, for example bis(1,5-cyclooctadienyl) nickel(0).

As alternatives to halogens as described above, leaving groups of formula —O—SO<sub>2</sub>Z<sup>1</sup> can be used wherein Z<sup>1</sup> is as described above. Particular examples of such leaving groups are tosylate, mesylate and triflate.

Especially suitable and preferred synthesis methods of the repeating units, monomers and polymers of the present invention are illustrated in the synthesis schemes shown below.

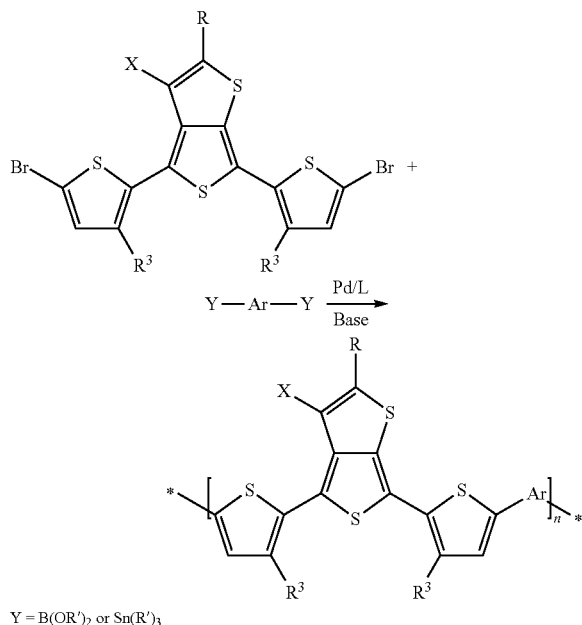
Therein, R and R<sup>3</sup> is preferably H, C<sub>m</sub>H<sub>2m+1</sub> (alkyl), COC<sub>m</sub>H<sub>2m+1</sub> (ketone) or COOC<sub>m</sub>H<sub>2m+1</sub> (ester), X is preferably H or F, m is preferably an integer from 1 to 20, Y is B(OR')<sub>2</sub>, Sn(R')<sub>3</sub> or ZnBr, and Ar and R' are as defined in formula III and IIIa.

Scheme 1: Synthesis of 4,6-di-thiophen-2-yl-thieno[3,4-b]thiophene



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Scheme 2: Synthesis of alternating co-polymers of 4,6-di-thiophen-2-yl-thieno[3,4-b]thiophene



The novel methods of preparing monomers and polymers as described above and below are another aspect of the invention.

The polymers according to the present invention can also be used in mixtures or polymer blends, for example together with monomeric compounds or together with other polymers having charge-transport, semiconducting, electrically conducting, photoconducting and/or light emitting semiconducting properties, or for example with polymers having hole blocking or electron blocking properties for use as interlayers or charge blocking layers in OLED devices. Thus, another aspect of the invention relates to a polymer blend comprising one or more polymers according to the present invention and one or more further polymers having one or more of the above-mentioned properties. These blends can be prepared by conventional methods that are described in prior art and known to the skilled person. Typically the polymers are mixed with each other or dissolved in suitable solvents and the solutions combined.

Another aspect of the invention relates to a formulation comprising one or more polymers, mixtures or polymer blends as described above and below and one or more organic solvents.

Preferred solvents are aliphatic hydrocarbons, chlorinated hydrocarbons, aromatic hydrocarbons, ketones, ethers and mixtures thereof. Additional solvents which can be used include 1,2,4-trimethylbenzene, 1,2,3,4-tetramethylbenzene, pentybenzene, mesitylene, cumene, cymene, cyclohexylbenzene, diethylbenzene, tetralin, decalin, 2,6-lutidine, 2-fluoro-m-xylene, 3-fluoro-o-xylene, 2-chlorobenzotrifluoride, dimethylformamide, 2-chloro-6-fluorotoluene, 2-fluoroanisole, anisole, 2,3-dimethylpyrazine, 4-fluoroanisole, 3-fluoroanisole, 3-trifluoro-methylanisole, 2-methylanisole, phenetol, 4-methylanisole, 3-methylanisole, 4-fluoro-3-methylanisole, 2-fluorobenzonitrile, 4-fluoroveratrol, 2,6-dimethylanisole, 3-fluorobenzonitrile, 2,5-dimethylanisole, 2,4-dimethylanisole, benzonitrile, 3,5-dimethylanisole, N,N-dimethylaniline, ethyl benzoate, 1-fluoro-3,5-dimethoxybenzene, 1-methylnaphthalene, N-methylpyrrolidinone, 3-fluorobenzotrifluoride, benzotri-

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luoride, benzotrifluoride, dioxane, trifluoromethoxybenzene, 4-fluorobenzotrifluoride, 3-fluoropyridine, toluene, 2-fluorotoluene, 2-fluorobenzotrifluoride, 3-fluorotoluene, 4-isopropylbiphenyl, phenyl ether, pyridine, 4-fluorotoluene, 2,5-difluorotoluene, 1-chloro-2,4-difluorobenzene, 2-fluoropyridine, 3-chlorofluorobenzene, 3-chlorofluorobenzene, 1-chloro-2,5-difluorobenzene, 4-chlorofluorobenzene, chlorobenzene, o-dichlorobenzene, 2-chlorofluorobenzene, p-xylene, m-xylene, o-xylene or mixture of o-, m-, and p-isomers. Solvents with relatively low polarity are generally preferred. For inkjet printing solvents with high boiling temperatures and solvent mixtures are preferred. For spin coating alkylated benzenes like xylene and toluene are preferred.

Examples of especially preferred solvents include, without limitation, dichloromethane, trichloromethane, monochlorobenzene, o-dichlorobenzene, tetrahydrofuran, anisole, morpholine, toluene, o-xylene, m-xylene, p-xylene, 1,4-dioxane, acetone, methylethylketone, 1,2-dichloroethane, 1,1,1-trichloroethane, 1,1,2,2-tetrachloroethane, ethyl acetate, n-butyl acetate, dimethylformamide, dimethylacetamide, dimethylsulfoxide, tetraline, decaline, indane, methyl benzoate, ethyl benzoate, mesitylene and/or mixtures thereof.

The concentration of the polymers in the solution is preferably 0.1 to 10% by weight, more preferably 0.5 to 5% by weight. Optionally, the solution also comprises one or more binders to adjust the rheological properties, as described for example in WO 2005/05248 A1.

After the appropriate mixing and ageing, solutions are evaluated as one of the following categories: complete solution, borderline solution or insoluble. The contour line is drawn to outline the solubility parameter-hydrogen bonding limits dividing solubility and insolubility. 'Complete' solvents falling within the solubility area can be chosen from literature values such as published in "Crowley, J. D., Teague, G. S. Jr and Lowe, J. W. Jr., Journal of Paint Technology, 38, No 496, 296 (1966)". Solvent blends may also be used and can be identified as described in "Solvents, W. H. Ellis, Federation of Societies for Coatings Technology, p 9-10, 1986". Such a procedure may lead to a blend of 'non' solvents that will dissolve both the polymers of the present invention, although it is desirable to have at least one true solvent in a blend.

The polymers according to the present invention can also be used in patterned OSC layers in the devices as described above and below. For applications in modern microelectronics it is generally desirable to generate small structures or patterns to reduce cost (more devices/unit area), and power consumption. Patterning of thin layers comprising a polymer according to the present invention can be carried out for example by photolithography, electron beam lithography or laser patterning.

For use as thin layers in electronic or electrooptical devices the polymers, polymer blends or formulations of the present invention may be deposited by any suitable method. Liquid coating of devices is more desirable than vacuum deposition techniques. Solution deposition methods are especially preferred. The formulations of the present invention enable the use of a number of liquid coating techniques. Preferred deposition techniques include, without limitation, dip coating, spin coating, ink jet printing, letter-press printing, screen printing, doctor blade coating, roller printing, reverse-roller printing, offset lithography printing, flexographic printing, web printing, spray coating, brush coating or pad printing. Ink-jet printing is particularly preferred as it allows high resolution layers and devices to be prepared.

Selected formulations of the present invention may be applied to prefabricated device substrates by ink jet printing or microdispensing. Preferably industrial piezoelectric print

heads such as but not limited to those supplied by Aprion, Hitachi-Koki, InkJet Technology, On Target Technology, Picojet, Spectra, Trident, Xaar may be used to apply the organic semiconductor layer to a substrate. Additionally semi-industrial heads such as those manufactured by Brother, Epson, Konica, Seiko Instruments Toshiba TEC or single nozzle microdispensers such as those produced by Microdrop and Microfab may be used.

In order to be applied by ink jet printing or microdispensing, the polymers should be first dissolved in a suitable solvent. Solvents must fulfil the requirements stated above and must not have any detrimental effect on the chosen print head. Additionally, solvents should have boiling points  $>100^{\circ}\text{C}$ ., preferably  $>140^{\circ}\text{C}$ . and more preferably  $>150^{\circ}\text{C}$ . in order to prevent operability problems caused by the solution drying out inside the print head. Apart from the solvents mentioned above, suitable solvents include substituted and non-substituted xylene derivatives, di- $\text{C}_{1-2}$ -alkyl formamide, substituted and non-substituted anisoles and other phenol-ether derivatives, substituted heterocycles such as substituted pyridines, pyrazines, pyrimidines, pyrrolidinones, substituted and non-substituted N,N-di- $\text{C}_{1-2}$ -alkylanilines and other fluorinated or chlorinated aromatics.

A preferred solvent for depositing a polymer according to the present invention by ink jet printing comprises a benzene derivative which has a benzene ring substituted by one or more substituents wherein the total number of carbon atoms among the one or more substituents is at least three. For example, the benzene derivative may be substituted with a propyl group or three methyl groups, in either case there being at least three carbon atoms in total. Such a solvent enables an ink jet fluid to be formed comprising the solvent with the polymer, which reduces or prevents clogging of the jets and separation of the components during spraying. The solvent(s) may include those selected from the following list of examples: dodecylbenzene, 1-methyl-4-tert-butylbenzene, terpineol limonene, isodurene, terpinolene, cymene, diethylbenzene. The solvent may be a solvent mixture, that is a combination of two or more solvents, each solvent preferably having a boiling point  $>100^{\circ}\text{C}$ ., more preferably  $>140^{\circ}\text{C}$ . Such solvent(s) also enhance film formation in the layer deposited and reduce defects in the layer.

The ink jet fluid (that is mixture of solvent, binder and semiconducting compound) preferably has a viscosity at  $20^{\circ}\text{C}$ . of 1-100 mPa·s, more preferably 1-50 mPa·s and most preferably 1-30 mPa·s.

The polymers or formulations according to the present invention can additionally comprise one or more further components or additives selected for example from surface-active compounds, lubricating agents, wetting agents, dispersing agents, hydrophobing agents, adhesive agents, flow improvers, defoaming agents, deaerators, diluents which may be reactive or non-reactive, auxiliaries, colourants, dyes or pigments, sensitizers, stabilizers, nanoparticles or inhibitors.

The polymers according to the present invention are useful as charge transport, semiconducting, electrically conducting, photoconducting or light emitting materials in optical, electrophotographic, electronic, electroluminescent or photoluminescent components or devices. In these devices, the polymers of the present invention are typically applied as thin layers or films.

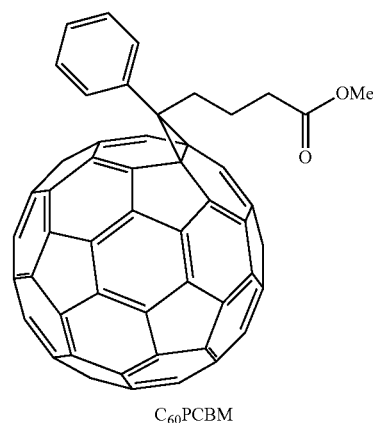
Thus, the present invention also provides the use of the semiconducting polymer, polymer blend, formulation or layer in an electronic device. The formulation may be used as a high mobility semiconducting material in various devices and apparatus. The formulation may be used, for example, in the form of a semiconducting layer or film. Accordingly, in

another aspect, the present invention provides a semiconducting layer for use in an electronic device, the layer comprising a polymer, polymer blend or formulation according to the invention. The layer or film may be less than about 30 microns. For various electronic device applications, the thickness may be less than about 1 micron thick. The layer may be deposited, for example on a part of an electronic device, by any of the aforementioned solution coating or printing techniques.

The invention additionally provides an electronic device comprising a polymer, polymer blend, formulation or organic semiconducting layer according to the present invention. Especially preferred devices are OFETs, TFTs, ICs, logic circuits, capacitors, RFID tags, OLEDs, OLETs, OPEDs, OPVs, solar cells, laser diodes, photoconductors, photodetectors, electrophotographic devices, electrophotographic recording devices, organic memory devices, sensor devices, charge injection layers, Schottky diodes, planarising layers, antistatic films, conducting substrates and conducting patterns.

Especially preferred electronic device are OFETs, OLEDs and OPV devices, in particular bulk heterojunction (BHJ) OPV devices. In an OFET, for example, the active semiconductor channel between the drain and source may comprise the layer of the invention. As another example, in an OLED device, the charge (hole or electron) injection or transport layer may comprise the layer of the invention.

For use in OPV devices the polymer according to the present invention is preferably used in a formulation that comprises or contains, more preferably consists essentially of, very preferably exclusively of, a p-type (electron donor) semiconductor and an n-type (electron acceptor) semiconductor. The p-type semiconductor is constituted by a polymer according to the present invention. The n-type semiconductor can be an inorganic material such as zinc oxide or cadmium selenide, or an organic material such as a fullerene derivative, for example (6,6)-phenyl-butyric acid methyl ester derivatized methano  $\text{C}_{60}$  fullerene, also known as "PCBM" or " $\text{C}_{60}\text{PCBM}$ ", as disclosed for example in G. Yu, J. Gao, J. C. Hummelen, F. Wudl, A. J. Heeger, Science 1995, Vol. 270, p. 1789 ff and having the structure shown below, or an structural analogous compound with e.g. a  $\text{C}_{70}$  fullerene group ( $\text{C}_{70}\text{PCBM}$ ), or a polymer (see for example Coakley, K. M. and McGehee, M. D. *Chem. Mater.* 2004, 16, 4533).



A preferred material of this type is a blend or mixture of a polymer according to the present invention with a  $\text{C}_{60}$  or  $\text{C}_{70}$  fullerene or modified fullerene like PCBM. Preferably the

ratio polymer:fullerene is from 2:1 to 1:2 by weight, more preferably from 1.2:1 to 1:1.2 by weight, most preferably 1:1 by weight. For the blended mixture, an optional annealing step may be necessary to optimize blend morphology and consequently OPV device performance.

The OPV device can for example be of any type known from the literature [see e.g. Waldauf et al., Appl. Phys. Lett. 89, 233517 (2006)].

A first preferred OPV device according to the invention comprises:

- a low work function electrode (11) (for example a metal, such as aluminum), and a high work function electrode (12) (for example ITO), one of which is transparent,
- a layer (13) (also referred to as "active layer") comprising a hole transporting material and an electron transporting material, preferably selected from OSC materials, situated between the electrodes (11,12); the active layer can exist for example as a bilayer or two distinct layers or blend or mixture of p-type and n-type semiconductor, forming a bulk heterojunction (BHJ) (see for example Coakley, K. M. and McGehee, M. D. *Chem. Mater.* 2004, 16, 4533),
- an optional conducting polymer layer (14), for example comprising a blend of PEDOT:PSS (poly(3,4-ethylenedioxythiophene): poly(styrenesulfonate)), situated between the active layer (13) and the high work function electrode (12), to modify the work function of the high work function electrode to provide an ohmic contact for holes,
- an optional coating (15) (for example of LiF) on the side of the low workfunction electrode (11) facing the active layer (13), to provide an ohmic contact for electrons.

A second preferred OPV device according to the invention is an inverted OPV device and comprises:

- a low work function electrode (21) (for example a metal, such as gold), and a high work function electrode (22) (for example ITO), one of which is transparent,
- a layer (23) (also referred to as "active layer") comprising a hole transporting material and an electron transporting material, preferably selected from OSC materials, situated between the electrodes (21,22); the active layer can exist for example as a bilayer or two distinct layers or blend or mixture of p-type and n-type semiconductor, forming a BHJ,
- an optional conducting polymer layer (24), for example comprising a blend of PEDOT:PSS, situated between the active layer (23) and the low work function electrode (21) to provide an ohmic contact for electrons,
- an optional coating (25) (for example of  $\text{TiO}_x$ ) on the side of the high workfunction electrode (22) facing the active layer (23), to provide an ohmic contact for holes.

In the OPV devices of the present invention the p-type and n-type semiconductor materials are preferably selected from the materials, like the polymer/fullerene systems, as described above. If the bilayer is a blend an optional annealing step may be necessary to optimize device performance.

The compound, formulation and layer of the present invention are also suitable for use in an OFET as the semiconducting channel. Accordingly, the invention also provides an OFET comprising a gate electrode, an insulating (or gate insulator) layer, a source electrode, a drain electrode and an organic semiconducting channel connecting the source and drain electrodes, wherein the organic semiconducting channel comprises a polymer, polymer blend, formulation or organic semiconducting layer according to the present invention. Other features of the OFET are well known to those skilled in the art.

OFETs where an OSC material is arranged as a thin film between a gate dielectric and a drain and a source electrode,

are generally known, and are described for example in U.S. Pat. No. 5,892,244, U.S. Pat. No. 5,998,804, U.S. Pat. No. 6,723,394 and in the references cited in the background section. Due to the advantages, like low cost production using the solubility properties of the compounds according to the invention and thus the processability of large surfaces, preferred applications of these FETs are such as integrated circuitry, TFT displays and security applications.

The gate, source and drain electrodes and the insulating and semiconducting layer in the OFET device may be arranged in any sequence, provided that the source and drain electrode are separated from the gate electrode by the insulating layer, the gate electrode and the semiconductor layer both contact the insulating layer, and the source electrode and the drain electrode both contact the semiconducting layer.

An OFET device according to the present invention preferably comprises:

- a source electrode,
- a drain electrode,
- a gate electrode,
- a semiconducting layer,
- one or more gate insulator layers,
- optionally a substrate.

wherein the semiconductor layer preferably comprises a polymer, polymer blend or formulation as described above and below.

The OFET device can be a top gate device or a bottom gate device. Suitable structures and manufacturing methods of an OFET device are known to the skilled in the art and are described in the literature, for example in US 2007/0102696 A1.

The gate insulator layer preferably comprises a fluoropolymer, like e.g. the commercially available Cytop 809M® or Cytop 107M® (from Asahi Glass). Preferably the gate insulator layer is deposited, e.g. by spin-coating, doctor blading, wire bar coating, spray or dip coating or other known methods, from a formulation comprising an insulator material and one or more solvents with one or more fluoro atoms (fluorosolvents), preferably a perfluorosolvent. A suitable perfluorosolvent is e.g. FC75® (available from Acros, catalogue number 12380). Other suitable fluoropolymers and fluorosolvents are known in prior art, like for example the perfluoropolymers Teflon AF®, 1600 or 2400 (from DuPont) or Fluoropel® (from Cytonix) or the perfluorosolvent FC 43® (Acros, No. 12377). Especially preferred are organic dielectric materials having a low permittivity (or dielectric constant) from 1.0 to 5.0, very preferably from 1.8 to 4.0 ("low k materials"), as disclosed for example in US 2007/0102696 A1 or U.S. Pat. No. 7,095,044.

In security applications, OFETs and other devices with semiconducting materials according to the present invention, like transistors or diodes, can be used for RFID tags or security markings to authenticate and prevent counterfeiting of documents of value like banknotes, credit cards or ID cards, national ID documents, licenses or any product with monetary value, like stamps, tickets, shares, cheques etc.

Alternatively, the materials according to the invention can be used in OLEDs, e.g. as the active display material in a flat panel display applications, or as backlight of a flat panel display like e.g. a liquid crystal display. Common OLEDs are realized using multilayer structures. An emission layer is generally sandwiched between one or more electron-transport and/or hole-transport layers. By applying an electric voltage electrons and holes as charge carriers move towards the emission layer where their recombination leads to the excitation and hence luminescence of the lumophor units contained in the emission layer. The inventive compounds, materials and films may be employed in one or more of the charge transport layers and/or in the emission layer, corresponding to their electrical and/or optical properties. Further-

more their use within the emission layer is especially advantageous, if the compounds, materials and films according to the invention show electroluminescent properties themselves or comprise electroluminescent groups or compounds. The selection, characterization as well as the processing of suitable monomeric, oligomeric and polymeric compounds or materials for the use in OLEDs is generally known by a person skilled in the art, see, e.g., Meerholz, *Synthetic Materials*, 111-112, 2000, 31-34, Alcalá, *J. Appl. Phys.*, 88, 2000, 7124-7128 and the literature cited therein.

According to another use, the materials according to this invention, especially those showing photoluminescent properties, may be employed as materials of light sources, e.g. in display devices, as described in EP 0 889 350 A1 or by C. Weder et al., *Science*, 279, 1998, 835-837.

A further aspect of the invention relates to both the oxidised and reduced form of the compounds according to this invention. Either loss or gain of electrons results in formation of a highly delocalised ionic form, which is of high conductivity. This can occur on exposure to common dopants. Suitable dopants and methods of doping are known to those skilled in the art, e.g. from EP 0 528 662, U.S. Pat. No. 5,198,153 or WO 96/21659.

The doping process typically implies treatment of the semiconductor material with an oxidating or reducing agent in a redox reaction to form delocalised ionic centres in the material, with the corresponding counterions derived from the applied dopants. Suitable doping methods comprise for example exposure to a doping vapor in the atmospheric pressure or at a reduced pressure, electrochemical doping in a solution containing a dopant, bringing a dopant into contact with the semiconductor material to be thermally diffused, and ion-implantation of the dopant into the semiconductor material.

When electrons are used as carriers, suitable dopants are for example halogens (e.g., I<sub>2</sub>, Cl<sub>2</sub>, Br<sub>2</sub>, ICl, ICl<sub>3</sub>, IBr and IF), Lewis acids (e.g., PF<sub>5</sub>, AsF<sub>5</sub>, SbF<sub>5</sub>, BF<sub>3</sub>, BCl<sub>3</sub>, SbCl<sub>5</sub>, BBr<sub>3</sub> and SO<sub>3</sub>), protonic acids, organic acids, or amino acids (e.g., HF, HCl, HNO<sub>3</sub>, H<sub>2</sub>SO<sub>4</sub>, HClO<sub>4</sub>, FSO<sub>3</sub>H and ClSO<sub>3</sub>H), transition metal compounds (e.g., FeCl<sub>3</sub>, FeOCl, Fe(ClO<sub>4</sub>)<sub>3</sub>, Fe(4-CH<sub>3</sub>C<sub>6</sub>H<sub>4</sub>SO<sub>3</sub>)<sub>3</sub>, TiCl<sub>4</sub>, ZrCl<sub>4</sub>, HfCl<sub>4</sub>, NbF<sub>5</sub>, NbCl<sub>5</sub>, TaCl<sub>5</sub>, MoF<sub>5</sub>, MoCl<sub>5</sub>, WF<sub>5</sub>, WCl<sub>6</sub>, UF<sub>6</sub> and LnCl<sub>3</sub> (wherein Ln is a lanthanoid), anions (e.g., Cl<sup>-</sup>, Br<sup>-</sup>, I<sup>-</sup>, I<sub>3</sub><sup>-</sup>, HSO<sub>4</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, NO<sub>3</sub><sup>-</sup>, ClO<sub>4</sub><sup>-</sup>, BF<sub>4</sub><sup>-</sup>, PF<sub>6</sub><sup>-</sup>, AsF<sub>6</sub><sup>-</sup>, SbF<sub>6</sub><sup>-</sup>, FeCl<sub>4</sub><sup>-</sup>, Fe(CN)<sub>6</sub><sup>3-</sup>, and anions of various sulfonic acids, such as aryl-SO<sub>3</sub><sup>-</sup>). When holes are used as carriers, examples of dopants are cations (e.g., H<sup>+</sup>, Li<sup>+</sup>, Na<sup>+</sup>, K<sup>+</sup>, Rb<sup>+</sup> and Cs<sup>+</sup>), alkali metals (e.g., Li, Na, K, Rb, and Cs), alkaline-earth metals (e.g., Ca, Sr, and Ba), O<sub>2</sub>, XeOF<sub>4</sub>, (NO<sub>2</sub><sup>+</sup>)(SbF<sub>6</sub><sup>-</sup>), (NO<sub>2</sub><sup>+</sup>)(SbCl<sub>6</sub><sup>-</sup>), (NO<sub>2</sub><sup>+</sup>)(BF<sub>4</sub><sup>-</sup>), AgClO<sub>4</sub>, H<sub>2</sub>IrCl<sub>6</sub>, La(NO<sub>3</sub>)<sub>3</sub>·6H<sub>2</sub>O, FSO<sub>2</sub>OOSO<sub>2</sub>F, Eu, acetylcholine, R<sub>4</sub>N<sup>+</sup>, (R is an alkyl group), R<sub>4</sub>P<sup>+</sup> (R is an alkyl group), R<sub>6</sub>As<sup>+</sup> (R is an alkyl group), and R<sub>3</sub>S<sup>+</sup> (R is an alkyl group).

The conducting form of the compounds of the present invention can be used as an organic "metal" in applications including, but not limited to, charge injection layers and ITO planarising layers in OLED applications, films for flat panel displays and touch screens, antistatic films, printed conductive substrates, patterns or tracts in electronic applications such as printed circuit boards and condensers.

The compounds and formulations according to the present invention may also be suitable for use in organic plasmon-emitting diodes (OPEDs), as described for example in Koller et al., *Nature Photonics* 2008 (published online Sep. 28, 2008).

According to another use, the materials according to the present invention can be used alone or together with other materials in or as alignment layers in LCD or OLED devices, as described for example in US 2003/0021913. The use of charge transport compounds according to the present inven-

tion can increase the electrical conductivity of the alignment layer. When used in an LCD, this increased electrical conductivity can reduce adverse residual dc effects in the switchable LCD cell and suppress image sticking or, for example in ferroelectric LCDs, reduce the residual charge produced by the switching of the spontaneous polarisation charge of the ferroelectric LCs. When used in an OLED device comprising a light emitting material provided onto the alignment layer, this increased electrical conductivity can enhance the electroluminescence of the light emitting material. The compounds or materials according to the present invention having mesogenic or liquid crystalline properties can form oriented anisotropic films as described above, which are especially useful as alignment layers to induce or enhance alignment in a liquid crystal medium provided onto said anisotropic film. The materials according to the present invention may also be combined with photoisomerisable compounds and/or chromophores for use in or as photoalignment layers, as described in US 2003/0021913.

According to another use the materials according to the present invention, especially their water-soluble derivatives (for example with polar or ionic side groups) or ionically doped forms, can be employed as chemical sensors or materials for detecting and discriminating DNA sequences. Such uses are described for example in L. Chen, D. W. McBranch, H. Wang, R. Helgeson, F. Wudl and D. G. Whitten, *Proc. Natl. Acad. Sci. U.S.A.* 1999, 96, 12287; D. Wang, X. Gong, P. S. Heeger, F. Rininsland, G. C. Bazan and A. J. Heeger, *Proc. Natl. Acad. Sci. U.S.A.* 2002, 99, 49; N. DiCesare, M. R. Pinot, K. S. Schanze and J. R. Lakowicz, *Langmuir* 2002, 18, 7785; D. T. McQuade, A. E. Pullen, T. M. Swager, *Chem. Rev.* 2000, 100, 2537.

Unless the context clearly indicates otherwise, as used herein plural forms of the terms herein are to be construed as including the singular form and vice versa.

Throughout the description and claims of this specification, the words "comprise" and "contain" and variations of the words, for example "comprising" and "comprises", mean "including but not limited to", and are not intended to (and do not) exclude other components.

It will be appreciated that variations to the foregoing embodiments of the invention can be made while still falling within the scope of the invention. Each feature disclosed in this specification, unless stated otherwise, may be replaced by alternative features serving the same, equivalent or similar purpose. Thus, unless stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

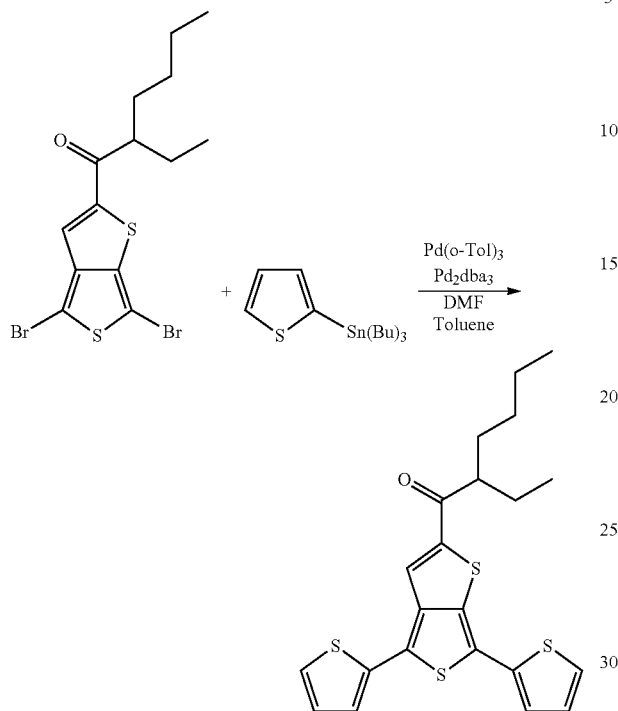
All of the features disclosed in this specification may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive. In particular, the preferred features of the invention are applicable to all aspects of the invention and may be used in any combination. Likewise, features described in non-essential combinations may be used separately (not in combination).

It will be appreciated that many of the features described above, particularly of the preferred embodiments, are inventive in their own right and not just as part of an embodiment of the present invention. Independent protection may be sought for these features in addition to or alternative to any invention presently claimed.

The invention will now be described in more detail by reference to the following examples, which are illustrative only and do not limit the scope of the invention.

**25**

Example 1

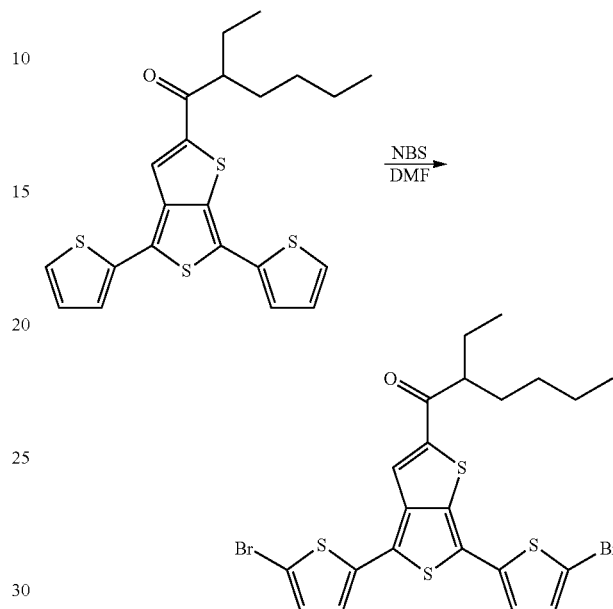
1-(4,6-Di-thiophen-2-yl-thieno[3,4-b]thiophen-2-yl)-  
2-ethyl-hexan-1-one

1-(4,6-Dibromo-thieno[3,4-b]thiophen-2-yl)-2-ethyl-hexan-1-one (6.500 g, 15.32 mmol), tributyl-thiophen-2-yl-stannane (10.70 cm<sup>3</sup>, 33.71 mmol), tri(o-tolyl)phosphine (0.373 g, 1.22 mmol), toluene (180 cm<sup>3</sup>) and dimethylformamide (20 cm<sup>3</sup>) were added to a 3-necked flask. The resulting mixture was carefully degassed for 30 minutes before adding tris(dibenzylideneacetone)dipalladium(0) (0.140 g, 0.153 mmol). The mixture was then stirred at 110° C. for 16 hours before being cooling down to 23° C. and the solvents were removed in vacuo. Purification by column chromatography (eluent petroleum ether 40-60/dichloromethane/triethylamine in 50:50:1 ratio) yielded a red oily product, which recrystallised upon standing (4.99 g, yield: 76%). NMR (<sup>1</sup>H, 300 MHz, CDCl<sub>3</sub>): δ 7.86 (s, 1H); 7.38 (dd, J<sub>1</sub>=4.6 Hz, J<sub>2</sub>=1.2

**26**

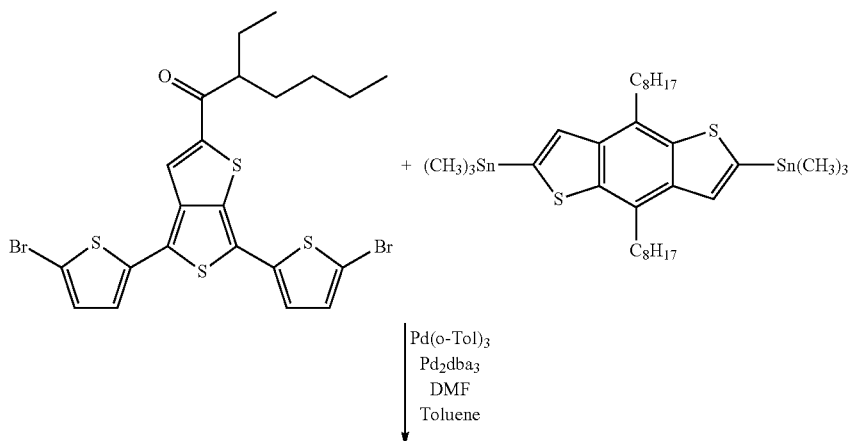
Hz, 1H); 7.32 (m, 2H), 7.38 (dd, J<sub>1</sub>=3.4 Hz, J<sub>2</sub>=1.2 Hz, 1H); 7.12 (m, 2H); 3.21 (m, 1H); 1.81 (m, 2H); 1.59 (m, 3H); 1.30 (m, 3H); 0.90 (m, 6H)

5 1-[4,6-Bis-(5-bromo-thiophen-2-yl)-thieno[3,4-b]thiophen-2-yl]-2-ethyl-hexan-1-one



1-(4,6-Di-thiophen-2-yl-thieno[3,4-b]thiophen-2-yl)-2-ethyl-hexan-1-one (3.184 g, 7.393 mmol) was dissolved in DMF (35 cm<sup>3</sup>). Under the protection of light, NBS (2.500 g, 14.05 mmol) was added in one portion. The reactant was stirred for 20 minutes and then poured into 100 cm<sup>3</sup> of 5% sodium thiosulfate solution with ice. The mixture was extracted into diethyl ether. Purification by column chromatography (eluent: petroleum ether 40-60/dichloromethane/triethylamine in 50:50:1 ratio) followed by recrystallization in a methanol/toluene mix. (3.470 g, yield: 80%). NMR (<sup>1</sup>H, 300 MHz, CDCl<sub>3</sub>): δ 7.74 (s, 1H); 7.08 (d, J=4.0 Hz, 1H); 7.03 (m, 2H), 7.38 (d, J=4.0 Hz, 1H); 3.21 (m, 1H); 1.81 (m, 2H); 1.59 (m, 3H); 1.30 (m, 3H); 0.90 (m, 6H)

Poly(2,6-[4,8-dioctyl-benzo{1,2-b;4,5-b'}dithiophene]-alt-[1-{4,6-Bis-(5-thiophen-2-yl)-thieno[3,4-b]thiophen-2-yl}-2-ethyl-hexan-1-one)



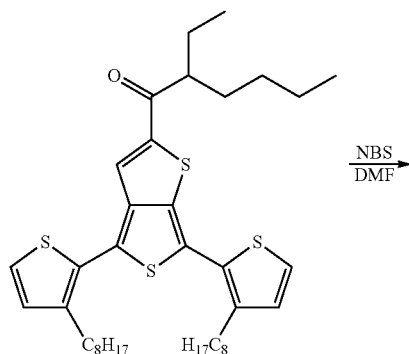




**29**

7.32 (d, J=5.2 Hz, 1H); 7.06 (d, J=5.3 Hz, 1H); 7.00 (d, J=5.3 Hz, 1H); 3.17 (m, 1H); 2.81 (m, 4H); 1.67 (m, 8H); 1.24 (m, 24H); 0.86 (m, 12H).

1-[4,6-Bis-(5-bromo-3-octyl-thiophen-2-yl)-thieno[3,4-b]thiophen-2-yl]-2-ethyl-hexan-1-one



NBS  
DMF

**30**

-continued

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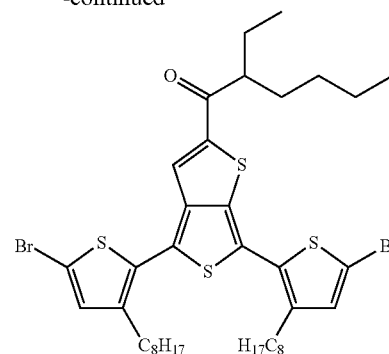
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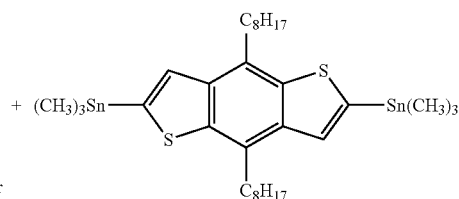
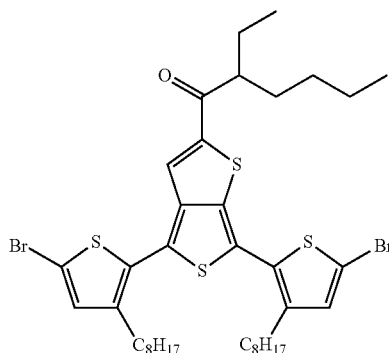
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1-[4,6-Bis-(3-octyl-thiophen-2-yl)-thieno[3,4-b]thiophen-2-yl]-2-ethyl-hexan-1-one (4.000 g, 6.106 mmol) is dissolved in anhydrous N,N-dimethylformamide (80 cm<sup>3</sup>). Under the protection of inert atmosphere, N-bromosuccinimide (2.065 g, 11.60 mmol) is added slowly in one portion. The reactant is stirred for 20 minutes and then poured into 100 cm<sup>3</sup> of 5% sodium thiosulfate solution with ice. The mixture is extracted by diethyl ether, dried over sodium sulfate and vacuum down. The crude product is purified several times by column chromatography using petroleum ether:DCM (65:35) as eluent to afford a red solid (2.950 g, yield: 59%). NMR (<sup>1</sup>H, 300 MHz, CDCl<sub>3</sub>): δ NMR (<sup>1</sup>H, 300 MHz, CDCl<sub>3</sub>): δ 7.76 (s, 1H); 7.02 (s, 1H); 6.96 (s, 1H); 3.17 (m, 1H); 2.73 (m, 4H); 1.65 (m, 8H); 1.24 (m, 24H); 0.85 (m, 12H).

Poly(2,6-[4,8-dioctyl-benzo{1,2-b;4,5-b'}dithiophene]-alt-5,5'-[4,6-bis-(3-octyl-thiophen-2-yl)-2-(2-ethyl-hexan-1-one)-thieno[3,4-b]thiophene])

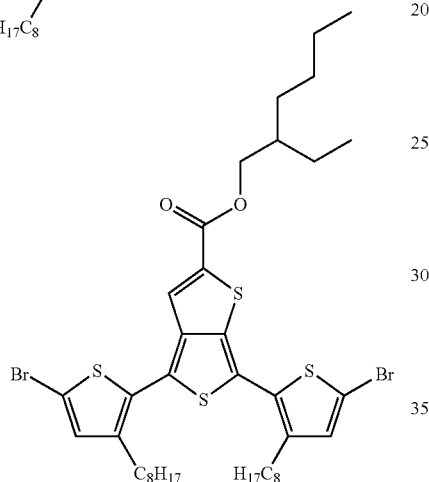
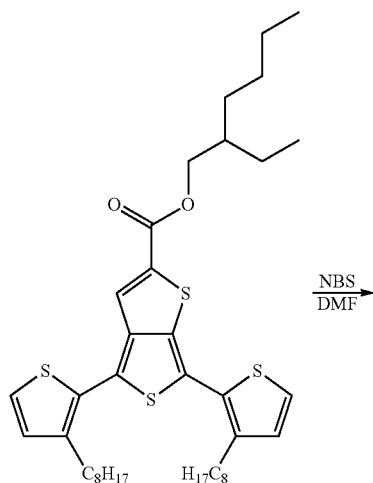


Pd(o-Tol)<sub>3</sub>  
Pd<sub>2</sub>dba<sub>3</sub>  
DMF  
Toluene



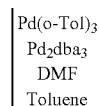
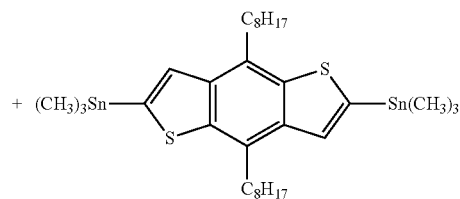
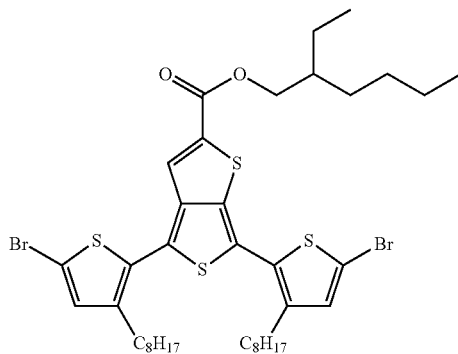
**33**

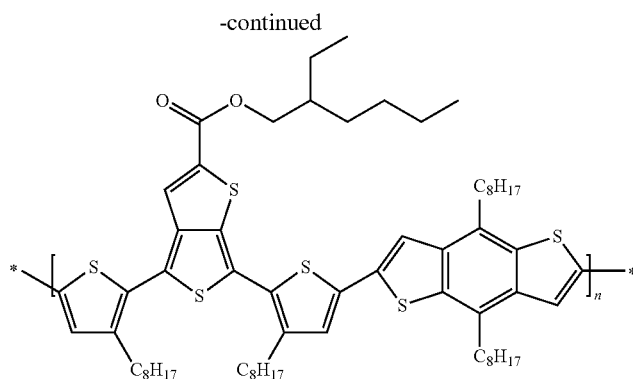
4,6-Bis-(5-bromo-3-octyl-thiophen-2-yl)-thieno[3,4-b]thiophene-2-carboxylic acid 2-ethyl-hexyl ester

**34**

4,6-Bis-(3-octyl-thiophen-2-yl)-thieno[3,4-b]thiophene-2-carboxylic acid 2-ethyl-hexyl ester (1.350 g; 1.970 mmol; 1.000 eq.) is dissolved in anhydrous N,N-dimethylformamide (40 cm<sup>3</sup>). Under the protection of inert atmosphere, N-bromosuccinimide (0.666 g; 3.74 mmol; 1.90 eq.) is added slowly in one portion. The reactants are stirred for 20 minutes and then poured into 50 cm<sup>3</sup> of 5% sodium thiosulfate solution with ice. The mixture is extracted by diethyl ether, dried over sodium sulfate and vacuum down. The crude product is purified by column chromatography using a mixture of petroleum ether and dichloromethane (80:20) as eluent to afford a red solid (1.243 g, yield: 75%). NMR (<sup>1</sup>H, 300 MHz, CDCl<sub>3</sub>): δ NMR (<sup>1</sup>H, 300 MHz, CDCl<sub>3</sub>): δ 7.77 (s, 1H); 6.99 (s, 1H); 6.96 (s, 1H); 4.24 (d, J=5.8 Hz, 2H); 2.72 (m, 4H); 1.63 (m, 5H); 1.24 (m, 28H); 0.86 (m, 12H).

Poly(2,6-[4,8-dioctyl-benzo{1,2-b;4,5-b'}dithiophene]-alt-5,5'-[4,6-bis-(3-octyl-thiophen-2-yl)-thieno[3,4-b]thiophene-2-carboxylic acid 2-ethylhexyl ester])





In a 50 cm<sup>3</sup> round bottom flask, 4,6-bis-(5-bromo-3-octylthiophen-2-yl)-thieno[3,4-b]thiophene-2-carboxylic acid 2-ethyl-hexyl ester (421.5 mg, 0.5000 mmol), 4,8-dioctyl-2,6-bis-trimethylstannanyl-benzo[1,2-b;4,5-b]dithiophene (370.1 mg, 0.5000) mmol, tris(dibenzylideneacetone)dipalladium(0) (2.3 mg, 2.5  $\mu$ mol) and tri(o-tolyl)phosphine (6.1 mg, 20  $\mu$ mol) are dissolved in degassed toluene (12.0 cm<sup>3</sup>) and degassed N,N-dimethylformamide (3.0 cm<sup>3</sup>). The reaction mixture is further degassed and the reaction mixture heated at 110° C. for 120 minutes. The polymer is purified by precipitation into methanol, filtered and washed sequentially via Soxhlet extraction with acetone, petroleum ether (40-60° C.), chloroform and chlorobenzene. The chlorobenzene fraction is reduced to a smaller volume in vacuo and precipitated into methanol (200 cm<sup>3</sup>). The precipitated polymer is filtered and dried under vacuum at 25° C. overnight to afford the title product (325 mg, yield 59%). GPC (140° C., 1,2,4-trichlorobenzene):  $M_n$ =43.6 kg·mol<sup>-1</sup>,  $M_w$ =91.6 kg·mol<sup>-1</sup>.

#### Use Example A

#### Bulk Heterojunction Organic Photovoltaic (BHJ OPV) Device

BHJ\_OPV devices are fabricated on ITO-glass substrates (13 $\Omega$ /), purchased from LUMTEC corporation. Substrates are cleaned using common solvents (acetone, IPA, DI water) in an ultrasonic bath prior to a conventional photolithography process is carried out to define the bottom electrodes (anodes).

A conducting polymer poly(ethylene dioxythiophene) doped with poly(styrene sulfonic acid) [Clevios VPAI 4083 (H. C. Starck)] is mixed on a 1:1 ratio with DI-water. This solution is sonicated for 20 minutes to ensure proper mixing and filtered using a 0.2  $\mu$ m filter and then is spin coated to a thickness of 20 nm. Substrates are exposed to ozone prior to the spin-coating process to ensure good wetting properties. Films are then annealed at 130° C. for 30 minutes in an inert atmosphere where they are kept for the rest of the process.

As photoactive material a mixture of the polymer of Example 2 or 3, respectively, and the fullerene compound PCBM-C<sub>60</sub> are used. Solutions of the photoactive material are prepared at the concentration and components ratio as shown in Table 1, and stirred overnight. Thin films of the solution are either spin coated or blade coated in an inert atmosphere to achieve thicknesses between 100 and 200 nm, measured using a profilometer. A short drying period followed to ensure removal of excess of solvent. Typically, spin coated films are dried at 23° C. for 10 minutes. Blade films are dried at 70° C. for 3 minutes on the hotplate.

As the last step of the device fabrication, Calcium (30 nm)/Al (200 nm) cathodes are thermally evaporated through a shadow mask to define cells.

Samples are measured at 23° C. using a Solar Simulator from Newport Ltd (model 91160) as light source and using a calibrated Si-cell as reference.

The device performances for the polymers of Example 2 and Example 3 are shown Table 1.

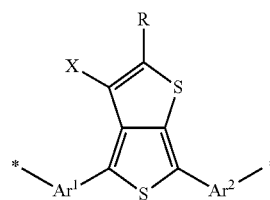
TABLE 1

Average open circuit potential ( $V_{oc}$ ), current density ( $J_{sc}$ ), fill factor (FF), power conversion efficiency (PCE) and best power conversion efficiency for Example 2 and PCBM-C <sub>60</sub> ratio and Example 3 and PCBM-C <sub>60</sub> ratio.								
Material	Ratio Polymer:PCBM	Conc. mg·ml <sup>-1</sup>	Voc mV	Jsc mA·cm <sup>-2</sup>	FF %	PCE %	PCE SD	Best PCE %
Ex. 2	1.0:1.5	30	605	-6.877	44.6	1.86	0.21	2.26
Ex. 2	1.0:2.0	30	500	-8.373	29.0	1.16	0.41	1.50
Ex. 2	1.0:2.5	30	620	-4.436	42.1	1.15	0.24	1.54
Ex. 3	1.0:1.5	30	557	-6.266	58.5	2.02	0.48	3.04
Ex. 3	1.0:2.0	30	542	-8.233	46.6	2.08	0.25	2.55
Ex. 3	1.0:2.5	30	518	-6.207	46.0	1.45	0.48	2.06

FIG. 1 shows typical J-V curves for a device containing a polymer of Example 2 (dashed line), and a device containing a polymer of Example 3 (continuous line), each having a ratio polymer:PCBM of 1.0:1.5.

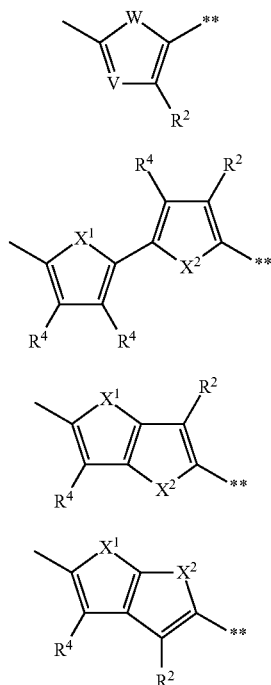
The invention claimed is:

1. Conjugated polymer comprising one or more identical or different repeating units of formula I

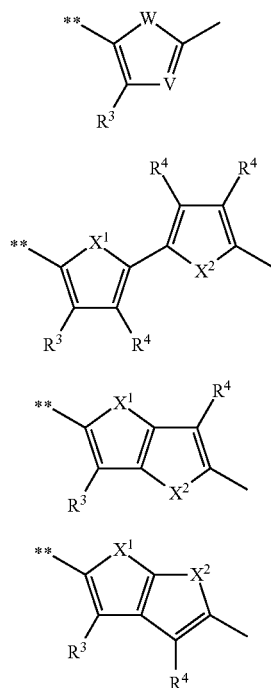


wherein the asterisks indicate a link to neighboring groups, Ar<sup>1</sup> is on each occurrence identically or differently a group selected from the following formulae

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Ar<sup>2</sup> is on each occurrence identically or differently a group selected from the following formulae



wherein \*\* indicates the position of attachment to the thienothiophene ring,  
W is S, Se or O,  
V is CH or N,  
X<sup>1</sup> and X<sup>2</sup> are, on each occurrence identically or differently, and independently of each other, O, S or Se

38

X is H or F,

IIa R on each occurrence identically or differently, denotes F, Cl, Br, I, CN, or straight-chain, branched or cyclic alkyl with 1 to 35 C atoms, in which one or more non-adjacent C atoms are optionally replaced by —O—, —S—, —CO—, —CO—O—, —O—CO—, —O—CO—O—, —CR<sup>0</sup>=CR<sup>00</sup>— or —C≡C— and in which one or more H atoms are optionally replaced by F, Cl, Br, I or CN, or denotes aryl, heteroaryl, aryloxy, heteroaryloxy, arylcarbonyl, heteroarylcarbonyl, arylcarbonyloxy, heteroarylcarbonyloxy, aryloxycarbonyl or heteroaryloxy-carbonyl having 4 to 30 ring atoms that is unsubstituted or substituted by one or more non-aromatic groups R<sup>1</sup>, R<sup>0</sup> and R<sup>00</sup> are independently of each other H or optionally substituted carbonyl or hydrocarbonyl optionally comprising one or more hetero atoms,

IIb R<sup>1</sup> is on each occurrence identically or differently H, halogen, —CN, —NC, —NCO, —NCS, —OCN, —SCN, —C(=O)NR<sup>0</sup>R<sup>00</sup>, —C(=O)X<sup>0</sup>, —C(=O)R<sup>0</sup>, —NH<sub>2</sub>, —NR<sup>0</sup>R<sup>00</sup>, —SH, —SR<sup>0</sup>, —SO<sub>3</sub>H, —SO<sub>2</sub>R<sup>0</sup>, —OH, —NO<sub>2</sub>, —CF<sub>3</sub>, —SF<sub>5</sub>, optionally substituted silyl, carbonyl or hydrocarbonyl with 1 to 40 C atoms that is optionally substituted and optionally comprises one or more hetero atoms, or P-Sp-,

IIc R<sup>2</sup> and R<sup>3</sup> on each occurrence identically or differently, and independently of each other, are selected from straight-chain alkyl, alkoxy and thioalkyl with 1 to 20 C atoms, or are selected from branched alkyl, alkoxy and thioalkyl with 3 to 20 C atoms, wherein in all the aforementioned groups one or more H atoms are optionally replaced by F, or are selected from aryloxy, heteroaryl or heteroaryloxy that is optionally alkylated or alkoxyated and has 4 to 30 ring atoms,

IId R<sup>4</sup> has on each occurrence identically or differently one of the meanings given for R or R<sup>1</sup>, P is a polymerisable or crosslinkable group, Sp is a spacer group or a single bond, X<sup>0</sup> is halogen.

IIe 2. Polymer according to claim 1, which is selected of formula III

IIIf



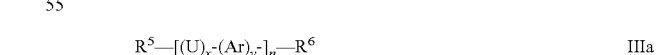
wherein U is on each occurrence identically or differently a unit of formula I as defined in claim 1,

IIg Ar is, on each occurrence identically or differently, an aryl or heteroaryl group that is optionally substituted,

x is on each occurrence identically or differently 0, 1 or 2, wherein in at least one repeating unit —[(U)<sub>x</sub>—(Ar)<sub>y</sub>—], x is 1,

y is on each occurrence identically or differently 0, 1 or 2, n is an integer > 1.

IIh 3. Polymer according to claim 2, which is selected of formula IIIa



wherein U, Ar, n, x and y have the meanings of claim 2, and R<sup>5</sup> and R<sup>6</sup> have independently of each other one of the meanings of R<sup>1</sup>, or denote H, —CH<sub>2</sub>Cl, —CHO, —CH=CH<sub>2</sub>, —SiR'R''R''', —SnR'R''R''', —BR'R'', —B(OR')(OR''), —B(OH)<sub>2</sub>, or P-Sp, wherein P and Sp are as defined above, and R', R'' and R''' are independently of each other H or optionally substituted carbonyl or hydrocarbonyl optionally comprising one or more hetero atoms or two of R', R'' and R''' may also form a ring together with the hetero atom to which they are attached.

4. Polymer according to claim 2, wherein x is 1 and y is 0 or 1.

5. Polymer according to claim 2, wherein Ar is selected from the group consisting of: 1,4-phenylene, thiophene-2,5-diyl, selenophene-2,5-diyl, thieno[3,2-b]thiophene-2,5-diyl, thieno[2,3-b]thiophene-2,5-diyl, selenopheno[3,2-b]selenophene-2,5-diyl, selenopheno[2,3-b]selenophene-2,5-diyl, selenopheno[3,2-b]thiophene-2,5-diyl, selenopheno[2,3-b]thiophene-2,5-diyl, benzo[1,2-b:4,5-b']dithiophene-2,6-diyl, 2,2-dithiophene, 2,2-diselenophene, dithieno[3,2-b:2',3'-d]silole-5,5-diyl, 4H-cyclopenta[2,1-b:3,4-b']dithiophene-2,6-diyl, carbazole-2,7-diyl, fluorene-2,7-diyl, indaceno[1,2-b:5,6-b']dithiophene-2,7-diyl, benzo[1",2":4,5;4",5":4',5']bis(silolo[3,2-b:3',2'-b']thiophene)-2,7-diyl, phenanthro[1,10,9,8-c,d,e,f,g]carbazole-2,7-diyl, benzo[2,1,3]thiadiazole-4,7-diyl, benzo[2,1,3]selenadiazole-4,7-diyl, benzo[2,1,3]oxadiazole-4,7-diyl, 2H-benzotriazole-4,7-diyl, 3,4-difluorothiophene-2,5-diyl, thieno[3,4-b]pyrazine-2,5-diyl, quinoxaline-5,8-diyl, thieno[3,4-b]thiophene-4,6-diyl, thieno[3,4-b]thiophene-6,4-diyl, 3,6-di-thien-2-yl-pyrrolo[3,4-c]pyrrole-1,4-dione, and [1,3]thiazolo[5,4-d][1,3]thiazole-2,5-diyl,

all of which are unsubstituted, or mono- or polysubstituted with R or R<sup>1</sup>.

6. Polymer according to claim 1, wherein R is —CO—R<sup>y</sup>, —CO—O—R<sup>y</sup>, or —O—CO—R<sup>y</sup>, wherein R<sup>y</sup> is straight-chain, branched or cyclic alkyl with 1 to 30 C atoms, in which one or more non-adjacent C atoms are optionally replaced by —O—, —S—, —CO—, —CO—O—, —O—CO—, —O—CO—O—, —CR<sup>0</sup>=CR<sup>00</sup>— or —C≡C— and in which one or more H atoms are optionally replaced by F, Cl, Br, I or CN, or R<sup>y</sup> is aryl, aryloxy, heteroaryl or heteroaryloxy having 4 to 30 ring atoms that is unsubstituted or substituted by one or more non-aromatic groups R<sup>1</sup> as defined in claim 1.

7. Polymer according to claim 1, wherein R<sup>4</sup>, when being different from H, is selected from straight-chain alkyl, alkoxy and thioalkyl with 1 to 20 C atoms, or is selected from branched alkyl, alkoxy and thioalkyl with 3 to 20 C atoms, wherein in all the aforementioned groups one or more H atoms are optionally replaced by F, or is selected from aryloxy, heteroaryl or heteroaryloxy that is optionally alkylated or alkoxyated and has 4 to 30 ring atoms.

8. Mixture or blend comprising one or more polymers according to claim 1 and one or more compounds or polymers having semiconducting, charge transport, hole/electron transport, hole/electron blocking, electrically conducting, photoconducting or light emitting properties.

9. Formulation comprising one or more polymers according to claim 1, and one or more solvents.

10. An optical, electrooptical, electronic, electroluminescent or photoluminescent component or device which comprises a polymer according to claim 1 as a charge transport, semiconducting, electrically conducting, photoconducting or light emitting material.

11. Optical, electrooptical or electronic component or device comprising a mixture or blend according to claim 8.

12. Component or device according to claim 11, which is selected from the group consisting of organic field effect transistors (OFET), thin film transistors (TFT), integrated circuits (IC), logic circuits, capacitors, radio frequency identification (RFID) tags, devices or components, organic light emitting diodes (OLED), organic light emitting transistors (OLET), flat panel displays, backlights of displays, organic photovoltaic devices (OPV), solar cells, laser diodes, photoconductors, photodetectors, electrophotographic devices, electrophotographic recording devices, organic memory

devices, sensor devices, charge injection layers, charge transport layers or interlayers in polymer light emitting diodes (PLEDs), Schottky diodes, planarising layers, antistatic films, polymer electrolyte membranes (PEM), conducting substrates, conducting patterns, electrode materials in batteries, alignment layers, biosensors, biochips, security markings, security devices, and components or devices for detecting and discriminating DNA sequences.

13. Component or device according to claim 11, which is an OFET or a bulk heterojunction OPV device.

14. Process of preparing a polymer according to claim 1 comprising coupling one or more monomers of formula Ia



wherein U is a unit of formula I as defined in claim 1, and R<sup>5</sup> and R<sup>6</sup> have independently of each other one of the meanings of R<sup>1</sup> in claim 1, or denote H, —CH<sub>2</sub>Cl, —CHO, —CH=CH<sub>2</sub>, —SiR'R''R''', —SnR'R''R''', —BR'R'', —B(OR')(OR''), —B(OH)<sub>2</sub>, or P-Sp, wherein P and Sp are as defined in claim 1, and R', R'' and R''' have independently of each other one of the meanings of R<sup>0</sup> in claim 1, or two of R', R'' and R''' may also form a ring together with the hetero atom to which they are attached,

with each other, and/or with one or more monomers of the formula



wherein Ar is, on each occurrence identically or differently, an aryl or heteroaryl group that is optionally substituted, in an aryl-aryl coupling reaction.

15. Polymer according to claim 6, wherein R is —CO—R<sup>y</sup> or —CO—O—R<sup>y</sup>.

16. Polymer according to claim 1, wherein the branched alkyl, alkoxy and thioalkyl with 3 to 20 C atoms option for R<sup>2</sup> and R<sup>3</sup> is secondary alkyl, alkoxy or thioalkyl with 3 to 20 C atoms or tertiary alkyl, alkoxy or thioalkyl with 4 to 20 C atoms.

17. Polymer according to claim 1, wherein R<sup>2</sup> and R<sup>3</sup> are independently selected from straight-chain alkyl, alkoxy and thioalkyl with 1 to 20 C atoms, or are selected from branched alkyl, alkoxy and thioalkyl with 3 to 20 C atoms, wherein in all the aforementioned groups one or more H atoms are optionally replaced by F.

18. Polymer according to claim 1, wherein:

R is primary alkyl, alkoxy or thioalkyl with 1 to 30 C atoms, secondary alkyl, alkoxy or thioalkyl with 3 to 30 C atoms, or tertiary alkyl, alkoxy or thioalkyl with 4 to 30 C atoms, wherein in all these groups one or more H atoms are optionally replaced by F,

or

R is —CO—R<sup>y</sup>, —CO—O—R<sup>y</sup>, or —O—CO—R<sup>y</sup>, wherein R<sup>y</sup> is straight-chain, branched or cyclic alkyl with 1 to 30 C atoms, in which one or more non-adjacent C atoms are optionally replaced by —O—, —S—, —CO—, —CO—O—, —O—CO—, —O—CO—O—, —CR<sup>0</sup>=CR<sup>00</sup>— or —C≡C— and in which one or more H atoms are optionally replaced by F, Cl, Br, I or CN.

19. Polymer according to claim 1, wherein, in formula IIa and IIe, W is S.

20. Polymer according to claim 1, wherein, in formula IIa and IIe, V is CH.

21. Polymer according to claim 1, wherein, in formula IIb to IIId and IIIf to IIh, X<sup>1</sup> and X<sup>2</sup> are S.